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INVENTION: OPTICAL WAVELENGTH DIVISION
            MULTIPLEX SIGNAL MONITORING APPARATUS

S P E C I F I C A T I O N

This application is based on Japanese Patent Application Nos. 2001-064042 filed March 7, 2001, and 2001-342257 filed November 7, 2001, the contents of which are incorporated hereinto by reference.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to an optical wavelength division multiplexed signal monitoring apparatus.

DESCRIPTION OF THE RELATED ART

Wavelength division multiplexing (WDM) is a technique that multiplexes a plurality of optical signal channels (called WDM channels from now on) with different carrier optical wavelengths into a single optical fiber and transmits them through the optical fiber. The technique is useful to deal with an increasing transmission capacity. The WDM technique includes the following as typical signal monitoring apparatuses.

Conventional technique 1: It identifies a faulty section and obtains a switching start signal for each WDM channel by carrying out parity check called bit interleaved parity between repeaters or multiplexing terminals by

using overhead specified in the synchronous optical network (SONET)/synchronous digital hierarchy (SDH) transmission scheme (reference material [1]: ITU-T Recommendation G.707).

5   Conventional technique 2: It observes an optical spectrum, and measures signal quality degradation for each WDM channel by monitoring an optical signal-to-noise ratio.

       FIG.1 shows a configuration of a wavelength division
10 multiplex signal monitoring apparatus of the conventional technique 1. The conventional signal monitoring apparatus comprises an optical wavelength division demultiplexer 61 for carrying out optical wavelength division demultiplexing of an optical wavelength division
15 multiplexed signal consisting of N optical signals with a bit rate f_0 (bits/s) which are wavelength multiplexed, (where N is an integer greater than one); and N electric signal processors 62 for processing N-channel optical wavelength division demultiplexed singals which are
20 demultiplexed by the optical wavelength division demultiplexer 61. Each electric signal processor 62 includes a photoelectric converter (receiving circuit) 63, a clock extracting section (clock extracting circuit) 64 and an error detecting section 65 consisting of a parity
25 check circuit or a comparing circuit. With an increase in the signal bit rate or variety of the signal formats for each WDM channel, the conventional technique 1 requires

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an increasing number of receiving systems (electric signal processors 62) suitable for the bit rate, signal format or modulation method (NRZ (Non Return to Zero) or RZ (Return to Zero)) of each signal. In addition, when the number

5 of the WDM channels increases by a factor of N, N receiving systems are required for each of them, thereby increasing the scale of the apparatus tremendously.

FIG.2 shows a configuration of a wavelength division multiplex signal monitoring apparatus of the conventional

10 technique 2. The conventional signal monitoring apparatus comprises an optical spectrum analyzer 62-1 for observing the optical spectrum of an optical wavelength division demultiplexed singal, and for measuring the signal quality degradation in each WDM channel by

15 monitoring the optical signal-to-noise ratio. Although the conventional technique 2 can obtain the optical signal-to-noise ratio, it has a problem in that it cannot detect the waveform degradation due to the wavelength dispersion in an optical fiber, or the transmission

20 degradation due to the waveform degradation by the polarization dispersion, and that it cannot reflect the bit error rate directly.

FIG.3 shows a configuration of a conventional example 3 of a wavelength division multiplex signal monitoring

25 apparatus. The conventional signal monitoring apparatus comprises a photoelectric converter 63 for converting a single-wavelength optical wavelength division

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demultiplexed singal into an electric intensity modulated signal; a sampling clock generator 66 for generating a sampling clock signal with a repetition frequency of f_1 (Hz) = $(n/m)f_0$ + a, where n and m are a natural number and

5   a is an offset frequency; and an electric signal processor 67.   The electric signal processor 67 samples the electric intensity modulated signal output from the photoelectric converter 63 by the sampling clock signal the sampling clock generator 66 generates, obtains optical signal

10   intensity distribution from the sampled signal, and evaluates an optical signal quality parameter on the basis of the optical signal intensity distribution.

FIG.4 shows a configuration of an example 4 of the conventional wavelength division multiplex signal

15   monitoring apparatus.   The conventional signal monitoring apparatus comprises an optical sampling pulse train generator 68; an optical multiplexer 69; a nonlinear optical medium 70; an optical splitter 71; a photoelectric converter 72; and an electric signal processor 73.   The

20   optical sampling pulse train generator 68 generates an optical sampling pulse train, the repetition frequency of which is f_1 = $(n/m)f_0$ + a, where n and m are a natural number and a is an offset frequency.   The pulse width of the pulses of the optical sampling pulse train is much narrower than

25   the time slot of an optical signal with a bit rate f_0 (bits/s).   The optical multiplexer 69 combines the optical wavelength division demultiplexed singal of a certain

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wavelength and the optical sampling pulse train generated by the optical sampling pulse train generator 68. The nonlinear optical medium 70 induces nonlinear interaction between the optical wavelength division demultiplexed

5   singal and the optical sampling pulse train, which are combined by the optical multiplexer 69. The optical splitter 71 splits a cross-correlation optical signal, which is brought about by the nonlinear interaction in the nonlinear optical medium 70, from the optical wavelength

10 division demultiplexed singal or from the optical sampling pulse train. The photoelectric converter 72, receiving the cross-correlation optical signal the optical splitter 71 outputs, converts it into the electric intensity modulated signal. The electric signal processor 73

15 calculates the optical signal intensity distribution from the electric intensity modulated signal supplied from the photoelectric converter 72, and evaluates the optical signal quality parameter on the basis of the optical signal intensity distribution.

20   The conventional examples as shown in FIGs. 3 and 4 are a method that evaluates the optical signal quality parameter from the amplitude histogram (reference material [2]: EPC publication No. EP0920150A2, US Patent application No. 09/204,001 which is not yet laid-open).

25 Although they can respond to an increase in the signal bit rate and an increase in the number of signal formats flexibly, and monitor the optical signal degradation such

as waveform degradation due to the wavelength dispersion in the optical fiber, they are not applicable to a multi-wavelength optical signal.

FIG.5 shows a configuration of an example 5 of the conventional wavelength division multiplex signal monitoring apparatus. It consists of the configurations of FIG.3, which are connected in parallel by the number of the WDM channels using an optical wavelength division demultiplexer 74. FIG.6 shows a configuration of an example 6 of the conventional wavelength division multiplex signal monitoring apparatus. As the example 5, it consists of the configurations of FIG.4, which are connected in parallel by the number of the WDM channels using an optical wavelength division demultiplexer 78.

The conventional examples 5 and 6 consist of the configurations of the conventional examples 3 and 4 in parallel by the number of the WDM channels. Accordingly, they have a problem in that when the number of the WDM channels is N, the scale of the apparatus increases by a factor of N.

On the other hand, the multimedia service market has boomed in recent years, and communication capacity of individual services must be increased. In addition, networks are required that satisfy a variety of signal bit rates and signal formats for the video, sound and data. Thus, an optical wavelength division multiplexed signal monitoring apparatus is required that can respond flexibly

to an increase in the number of the WDM channels, an increase in the signal bit rate per WDM channel, and diversification of the signal format. In connection with this, the optical signal degradation factors to be monitored are also diversified. In particular, it is necessary to monitor the waveform degradation involved in the wavelength dispersion in the optical fiber, and the waveform degradation due to the polarization dispersion.

Therefore, an optical wavelength division multiplexed signal monitoring apparatus is eagerly required that can monitor the optical signal degradation factors such as waveform degradation involved in the wavelength dispersion in the optical fiber, and can respond flexibly to an increase in the number of the WDM channels, an increase in the signal bit rate of each WDM channel, and the diversification of the signal formats.

SUMMARY OF THE INVENTION

The present invention is implemented to solve the foregoing problems. Therefore, an object of the present invention is to provide an optical wavelength division multiplexed signal monitoring apparatus capable of shrinking its size by reducing into one system an electric signal processing unit for evaluating an optical signal quality parameter on the basis of the optical signal intensity distribution, and by processing the plurality

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of wavelength channels at a time.

Another object of the present invention is to provide an optical wavelength division multiplexed signal monitoring apparatus capable of monitoring optical signal quality degradation such as SNR degradation and waveform distortion by a single circuit regardless of the bit rate, signal format and modulation method of the target optical wavelength division multiplexed signal to be measured.

To accomplish the foregoing objects, the optical wavelength division multiplexed signal monitoring apparatus in accordance with the present invention is characterized by the apparatus comprising optical wavelength division demultiplexing means for carrying out optical wavelength division demultiplexing of an optical wavelength division multiplexed signal including N optical signals with a bit rate f_0 (bits/s), which are wavelength multiplexed, where N is an integer greater than one, one or N opto-electric conversion means for receiving optical wavelength division demultiplexed singals demultiplexed by the optical wavelength division demultiplexing means, and for converting the optical wavelength division demultiplexed singals into electric intensity modulated signals, and electric signal processing means for carrying out optical signal quality evaluation based on the electric intensity modulated signals output from the opto-electric conversion means, the electric signal processing means is a single system.

Preferably, the electric signal processing means has N inputs, stores N channel electric signals supplied from the N opto-electric conversion means by N buffers for a predetermined time period, and processes the electric signals by sequentially reading them from the buffers.

Preferably, the electric signal processing means has N inputs, and processes N channel analog electric signals supplied from the N opto-electric conversion means by sequentially reading the analog electric signals by sequentially switching connections with the analog electric signals.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises sampling clock generating means for generating a sampling clock signal whose repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency), the electric signal processing means samples N-channel electric intensity modulated signals supplied from the N opto-electric conversion means by the sampling clock signal generated by the sampling clock generating means, obtains optical signal intensity distribution from sampled signals generated thereby, and evaluates an optical signal quality parameter for each of the N channels based on the optical signal intensity distribution.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises

optical sampling pulse train generating means for
generating an optical sampling pulse train whose
repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where
n and m are a natural number, and a is an offset frequency)

5 and whose pulse width is sufficiently narrower than a time
slot of the optical signal with the bit rate f_0 (bits/s),
optical sampling pulse train splitting means for splitting
the optical sampling pulse train generated from the
optical sampling pulse train generating means into N

10 sequences, N optical combining means for combining N-
channel optical wavelength division demultiplexed singals
demultiplexed by the optical wavelength division
demultiplexing means with N sequence optical sampling
pulse trains spitted by the optical sampling pulse train

15 splitting means, N nonlinear optical media for inducing
nonlinear interaction between the optical sampling pulse
trains and the optical wavelength division demultiplexed
singals combined by the optical combining means, and N
optical splitting means for splitting cross-correlation

20 optical signals generated by the nonlinear interaction in
the nonlinear optical media from the optical wavelength
division multiplexed signal and from the optical sampling
pulse trains, the opto-electric conversion means consists
of N opto-electric conversion means for receiving the

25 N-channel cross-correlation optical signals splitted by
the optical splitting means, and for converting the N-
channel cross-correlation optical signals into electric

intensity modulated signals, and the electric signal processing means obtains optical signal intensity distribution from the N-channel electric intensity modulated signals outputted by the opto-electric conversion means, and evaluates an optical signal quality parameter for each of the N channels based on the optical signal intensity distribution.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises sampling clock generating means for generating a sampling clock signal whose repetition frequency f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency), and N optical gating means, each of which is disposed for one of N channels, for sampling intensities of optical wavelength division demultiplexed singals with a bit rate of f_0 (bits/s), which are demultiplexed by the optical wavelength division demultiplexing means by using the sampling clock signal generated by the sampling clock generating means,

the N opto-electric conversion means receive optical signals sampled by the optical gating means disposed for respective channels, and convert the optical signals into electric intensity modulated signals.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises sampling clock generating means for generating a sampling clock signal whose repetition frequency f_1 (Hz) ($f_1 =

$(n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency), and single optical gating means for sampling N channels of the optical wavelength division multiplexed signal all at once by the sampling clock signal

5   generated by the sampling clock generating means, before carrying out optical wavelength division demultiplexing, the optical wavelength division demultiplexing means carries out optical wavelength division of the optical gating signal produced by the optical gating means.

10   Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises optical sampling pulse train generating means for generating an optical sampling pulse train whose repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where

15   n and m are a natural number, and a is an offset frequency) and whose pulse width is sufficiently narrower than a time slot of the optical signal with the bit rate f_0 (bits/s), optical combining means for multiplexing an optical sampling pulse train generated by the optical sampling

20   pulse train generating means with an optical wavelength division multiplexed signal consisting of N optical signals with a bit rate f_0 (bits/s), which are wavelength multiplexed, where N is an integer greater than one, and   nonlinear optical medium for inducing nonlinear

25   interaction between the optical sampling pulse train and the optical wavelength division multiplexed signal, which are combined by the optical combining means, the optical

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wavelength division demultiplexing means carries out wavelength division demultiplexing of a cross-correlation optical signal, which is generated by the nonlinear interaction in the nonlinear optical medium, into N

5 channels, the opto-electric conversion means consists of N opto-electric conversion means for receiving the N-channel cross-correlation optical signals output from the optical wavelength division demultiplexing means, and for converting them into N-channel electric intensity

10 modulated signals, and the electric signal processing means obtains optical signal intensity distribution from the N-channel electric intensity modulated signals the N opto-electric conversion means output, and evaluates an optical signal quality parameter for each of the N-channels

15 from the optical signal intensity distribution.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises wavelength selection means disposed before the electric signal processing means for making wavelength selection

20 by wavelength division demultiplexing to reduce a number of inputs to the electric signal processing means to one, the electric signal processing means stores an electric signal supplied from the one opto-electric conversion means by a single buffer for a predetermined time period,

25 and processes the electric signal by reading it from the buffer.

Preferably, the optical wavelength division

multiplexed signal monitoring apparatus further comprises optical wavelength selection means for selecting and carrying out optical wavelength division demultiplexing of any one of channels of the optical wavelength division

5 multiplexed signal consisting of N optical signals with a bit rate f_0 (bits/s), which are wavelength multiplexed, where N is an integer greater than one, and selection wavelength control means for controlling a wavelength to be selected by the optical wavelength selection means, and

10 sampling clock generating means for generating a sampling clock signal with a repetition frequency f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency), the opto-electric conversion means consists of single opto-electric conversion means

15 for receiving optical wavelength division demultiplexed singal the optical wavelength selection means selects and demultiplexes, and converts it into an electric intensity modulated signal, and the electric signal processing means samples the one-channel electric intensity modulated

20 signal the opto-electric conversion means outputs by using the sampling clock signal the sampling clock generating means generates, obtains optical signal intensity distribution from a sampled signal obtained, and evaluates an optical signal quality parameter from the optical signal

25 intensity distribution.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus as claimed in

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claim 4, further comprises optical wavelength selection means for selecting and carrying out optical wavelength division demultiplexing of any one of channels of the optical wavelength division multiplexed signal consisting of N optical signals with a bit rate f_0 (bits/s), which are wavelength multiplexed, where N is an integer greater than one, selection wavelength control means for controlling a wavelength to be selected by the optical wavelength selection means, sampling clock generating means for generating a sampling clock signal with a repetition frequency f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency), and single optical gating means for sampling intensity of the one-channel optical wavelength division demultiplexed singal the optical wavelength selection means selects and demultiplexes by using the sampling clock signal the sampling clock generating means generates, the opto-electric conversion means consists of single opto-electric conversion means for receiving one-channel optical gate signal the optical gating means outputs, and converts it into an electric intensity modulated signal, and the electric signal processing means obtains optical signal intensity distribution from the one-channel electric intensity modulated signal, and evaluates an optical signal quality parameter from the optical signal intensity distribution.

Preferably, the optical wavelength division

multiplexed signal monitoring apparatus further comprises optical wavelength selection means for selecting and carrying out optical wavelength division demultiplexing of any one of channels of the optical wavelength division

5   multiplexed signal consisting of N optical signals with a bit rate f_0 (bits/s), which are wavelength multiplexed, where N is an integer greater than one, selection wavelength control means for controlling a wavelength to be selected by the optical wavelength selection means,

10   optical sampling pulse train generating means for generating an optical sampling pulse train whose repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency) and whose pulse width is sufficiently narrower than a time

15   slot of the optical signal with the bit rate f_0 (bits/s), optical combining means for combining the optical sampling pulse train the optical sampling pulse train generating means generates with one-channel optical wavelength division demultiplexed singal the optical wavelength

20   selection means selects and demultiplexes, single nonlinear optical medium for inducing nonlinear interaction between the optical sampling pulse train and the optical wavelength division demultiplexed singal, which are combined by the optical combining means, and

25   single optical splitting means for splitting a cross-correlation optical signal generated by the nonlinear interaction in the nonlinear optical medium from the

optical wavelength division demultiplexed singal and from
the optical sampling pulse train,   the opto-
electric conversion means consists of single opto-electric
conversion means for receiving the one-channel cross-

5   correlation optical signal the optical splitting means
outputs, and converts it into an electric intensity
modulated signal, and the electric signal processing means
obtains optical signal intensity distribution from the
one-channel electric intensity modulated signal the

10 opto-electric conversion means produces, and evaluates the
optical signal quality parameter from the optical signal
intensity distribution.

Preferably, the optical wavelength division
multiplexed signal monitoring apparatus further comprises

15 sampling clock generating means for generating a sampling
clock signal with a repetition frequency f_1 (Hz) ($f_1 =$
$(n/m)f_0 + a$, where n and m are a natural number, and a is
an offset frequency), single optical gating means for
sampling intensity of an optical wavelength division

20 multiplexed signal with a bit rate f_0 (bits/s) consisting
of N optical signals which are wavelength multiplexed,
where N is an integer greater than one, by using the
sampling clock signal the sampling clock generating means
generates, optical wavelength selection means for

25 selecting and carrying out optical wavelength division
demultiplexing of any one of channels of one-channel
optical gating signal the optical gating means outputs,

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and   selection wavelength control means for controlling a wavelength to be selected by the optical wavelength selection means, the opto-electric conversion means consists of single opto-electric conversion means for receiving one-channel optical wavelength division demultiplexed singal the optical wavelength selection means selects and demultiplexes, and converts it into an electric intensity modulated signal, and the electric signal processing means receives optical signal intensity distribution from the one-channel electric intensity modulated signal the opto-electric conversion means outputs, and evaluates an optical signal quality parameter from the optical signal intensity distribution.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises optical sampling pulse train generating means for generating an optical sampling pulse train whose repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency) and whose pulse width is sufficiently narrower than a time slot of the optical signal with the bit rate f_0 (bits/s), optical combining means for combining an optical sampling pulse train the optical sampling pulse train generating means generates with an optical wavelength division multiplexed signal consisting of N optical signals with the bit rate f_0 (bits/s), which are wavelength multiplexed, where N is an integer greater than one, single nonlinear

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optical medium for inducing nonlinear interaction between
the optical sampling pulse train and the optical wavelength
division multiplexed signal, which are combined by the
optical combining means, optical wavelength selection
5   means for selecting and carrying out optical wavelength
division demultiplexing any one of channels of N-channel
cross-correlation optical signals generated by the
nonlinear interaction in the nonlinear optical medium, and
selection wavelength control means for controlling a
10   wavelength to be selected by the optical wavelength
selection means, the opto-electric conversion means
consists of single opto-electric conversion means for
receiving one-channel optical wavelength division
demultiplexed singal the optical wavelength selection
15   means selects and demultiplexes, and converts it into an
electric intensity modulated signal, and the electric
signal processing means receives optical signal intensity
distribution from the one-channel electric intensity
modulated signal the opto-electric conversion means
20   outputs, and evaluates an optical signal quality parameter
from the optical signal intensity distribution.

Preferably, the optical wavelength division
multiplexed signal monitoring apparatus further comprises
polarization control means for controlling a polarization
25   state of all channels of the optical wavelength division
multiplexed signal in their entirety, wherein the
polarization control means controls the polarization state

of all channels such that it maintains a fixed polarization relationship with a polarization state of the optical sampling pulse train said optical sampling pulse train generating means outputs, or with a polarization

5   dependence of said optical gating means.

Preferably, the optical wavelength division multiplexed signal monitoring apparatus further comprises optical signal wavelength dispersion control means for controlling wavelength dispersion of the optical

10   wavelength division multiplexed signal to compensate for wavelength dispersion of all channels of the optical wavelength division multiplexed signal in their entirety.

Preferably, the electric signal processing means is disposed in an optical signal receive terminal, and

15   comprises a signal-to-noise ratio coefficient measuring section for measuring a signal-to-noise ratio coefficient of an optical signal transmitted on an optical signal route between an optical signal transmit terminal of a first optical node and an optical signal receive terminal of a

20   second optical node, an initial state storing section for storing an initial signal-to-noise ratio coefficient the signal-to-noise ratio coefficient measuring section measures in a state without any failure at a system installation, and an optical signal quality evaluating

25   section for comparing the initial signal-to-noise ratio coefficient stored in the initial state storing section with a signal-to-noise ratio coefficient the signal-

to-noise ratio coefficient measuring section measures at every predetermined time interval during system operation, the optical wavelength division multiplexed signal monitoring apparatus carries out analog monitoring

5   independent of an optical signal modulation method, format and bit rate.

Preferably, the signal-to-noise ratio coefficient measuring section comprises optical signal intensity distribution measurement means for measuring intensity

10   distribution of the optical signal by sampling intensity of the electric intensity modulated signal at a clock signal frequency f_1 (Hz) ($f_1 = (N/M)f_0 + a$, where N and M are positive numbers, and a is an offset frequency), and signal-to-noise ratio coefficient evaluation means for

15   evaluating the signal-to-noise ratio coefficient using an amplitude histogram obtained from the optical signal intensity distribution within a mean time, and the signal-to-noise ratio coefficient evaluation means comprises histogram evaluation means for obtaining the

20   amplitude histogram from the intensity distribution of the optical signal within the mean time, distribution function evaluation means for estimating an amplitude histogram distribution function g1 corresponding to "level 1" from an amplitude histogram portion that is greater than a

25   predetermined intensity threshold value A, and for estimating an amplitude histogram distribution function g0 corresponding to "level 0" from an amplitude histogram

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portion that is smaller than another predetermined

intensity threshold value B; and optical signal quality

evaluation means for obtaining mean value intensities and

standard deviations of the "level 1" and "level 0" from

5 the amplitude histogram distribution functions g1 and g0,

and for evaluating the signal-to-noise ratio coefficient

that is obtained as a ratio of a difference between the

mean value intensities of the "level 1" and "level 0" to

a sum of the standard deviations at the "level 1" and "level

10 0".

Preferably, the distribution function evaluation

means obtains two relative maximum values from the

amplitude histogram obtained from the intensity

distribution of the optical signal to be measured, and

15 makes the relative maximum value with greater amplitude

intensity the intensity threshold value A, and the relative

maximum value with smaller amplitude intensity the

intensity threshold value B.

As described above, the present invention expands the

20 method of monitoring the optical signal quality

degradation such as SNR degradation and waveform

distortion by a single circuit regardless of the signal

bit rate, signal format and modulation method to the

optical wavelength division multiplexed signal of N

25 wavelengths by using the optical wavelength division

demultiplexing means. According to the present invention,

since the electric signal processing that evaluates the

optical signal quality parameter from the optical signal intensity distribution has no wavelength dependence, only one electric signal processing unit is enough to perform the signal processing, thereby being able to reduce the size of the apparatus.

Besides, according to the present invention, the single circuit can monitor the optical signal quality degradation such as SNR degradation and waveform distortion regardless of the bit rate, signal format and modulation method of the target optical wavelength division multiplexed signal to be measured.

Furthermore, when nonlinear optical mediums are used in the present invention, it is not necessary for each of the nonlinear optical mediums to have a wide bandwidth because it can only handle the wavelength of the incident optical signal. In addition, although the nonlinear optical mediums as a whole must be applicable to all the optical signal wavelengths (wide bandwidth), since the optical combining means, nonlinear optical mediums, and opto-electric conversion means can each be composed of only one unit, the entire configuration can be simplified.

Moreover, the present invention can increase the range of the optical signal bit rate by using the optical sampling method as compared with the method using the electric sampling.

The above and other objects, effects, features and advantages of the present invention will become more

apparent from the following description of embodiments thereof taken in conjunction with the accompanying drawings.

5   BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing a configuration of an example 1 of the conventional optical wavelength division multiplexed signal monitoring apparatus;

10   FIG. 2 is a block diagram showing a configuration of an example 2 of the conventional optical wavelength division multiplexed signal monitoring apparatus;

FIG. 3 is a block diagram showing a configuration of an example 3 of the conventional optical wavelength

15   division multiplexed signal monitoring apparatus;

FIG. 4 is a block diagram showing a configuration of an example 4 of the conventional optical wavelength division multiplexed signal monitoring apparatus;

FIG. 5 is a block diagram showing a configuration of

20   an example 5 of the conventional optical wavelength division multiplexed signal monitoring apparatus;

FIG. 6 is a block diagram showing a configuration of an example 6 of the conventional optical wavelength division multiplexed signal monitoring apparatus;

25   FIG. 7 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a first embodiment in accordance

with the present invention;

FIG. 8 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a second embodiment in accordance with the present invention;

FIG. 9 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a third embodiment in accordance with the present invention;

FIG. 10 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a fourth embodiment in accordance with the present invention;

FIG. 11 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a fifth embodiment in accordance with the present invention;

FIG. 12 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a sixth embodiment in accordance with the present invention;

FIG. 13 is a diagram illustrating an example of a level measuring method of a light intensity histogram an electric signal processor measures of optical wavelength division multiplexed signal monitoring apparatus of a sixth embodiment in accordance with the present invention;

FIG. 14 is a block diagram showing a first

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configuration of an optical gating section of the optical wavelength division multiplexed signal monitoring apparatus of the sixth embodiment in accordance with the present invention;

5   FIG. 15 is a block diagram showing a second configuration of an optical gating section of the optical wavelength division multiplexed signal monitoring apparatus of the sixth embodiment in accordance with the present invention;

10   FIG. 16 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a seventh embodiment in accordance with the present invention;

FIG. 17 is a block diagram showing a configuration of an optical wavelength division multiplexed signal
15   monitoring apparatus of an eighth embodiment in accordance with the present invention;

FIG. 18 is a block diagram showing a configuration of an optical wavelength division multiplexed signal
20   monitoring apparatus of a ninth embodiment in accordance with the present invention;

FIG. 19 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a 10th embodiment in accordance
25   with the present invention;

FIG. 20 is a block diagram showing a configuration of an optical wavelength division multiplexed signal

monitoring apparatus of an 11th embodiment in accordance with the present invention;

FIG. 21 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a 12th embodiment in accordance with the present invention;

FIG. 22 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a 13th embodiment in accordance with the present invention;

FIG. 23 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a 14th embodiment in accordance with the present invention;

FIG. 24 is a block diagram showing a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a 15th embodiment in accordance with the present invention;

FIGs. 25A and 25B are block diagrams showing a configuration of an optical network of a 16th embodiment in accordance with the present invention, wherein FIG. 25A shows an optical network with a ring configuration including a standby circuit, and FIG. 25B shows an optical network with a mesh configuration;

FIG 26 is a diagram showing the relationship of FIGs. 26A and 26B;

FIGs. 26A and 26B are block diagrams showing a

configuration of an optical transmit/receive terminal 104
of the 16th embodiment in accordance with the present
invention;

FIG. 27 is a flowchart illustrating a procedure of
route control in an optical signal monitoring system of
the 16th embodiment in accordance with the present
invention;

FIG. 28 is a block diagram showing a configuration
of a signal-to-noise ratio coefficient measuring section
when using an electrical sampling oscilloscope in the
individual embodiments in accordance with the present
invention;

FIG. 29 is a block diagram showing a configuration
of a signal-to-noise ratio coefficient measuring section
when using an optical sampling oscilloscope in the
individual embodiments in accordance with the present
invention;

FIGs. 30A and 30B are schematic diagrams illustrating
an initial stage of signal-to-noise ratio coefficient
measuring algorithm of the 16th embodiment in accordance
with the present invention;

FIGs. 31A and 31B are schematic diagrams illustrating
the signal-to-noise ratio coefficient measuring algorithm
following that of FIGs. 30A and 30B in the 16th embodiment
in accordance with the present invention;

FIGs. 32A and 32B are schematic diagrams illustrating
the signal-to-noise ratio coefficient measuring algorithm

following that of FIGs. 31A and 31B in the 16th embodiment in accordance with the present invention;

FIGs. 33A and 33B are schematic diagrams illustrating the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 32A and 32B in the 16th embodiment in accordance with the present invention;

FIG. 34 is a graph illustrating experimental data of the signal-to-noise ratio coefficient obtained in the procedure as illustrating FIGs. 30A-33B, where the horizontal axis represents Q values obtained by converting the bit error rate measured, and the vertical axis represents the signal-to-noise ratio coefficients obtained by the algorithm of FIGs. 30A-33B;

FIG. 35 is a graph illustrating experimental data when the wavelength dispersion has effect, where the horizontal axis represents Q values obtained by converting the bit error rate measured, and the vertical axis represents the signal-to-noise ratio coefficients obtained by the algorithm of FIGs. 30A-33B;

FIGs. 36A and 36B are block diagrams showing a configuration of an optical network of a 17th embodiment in accordance with the present invention, wherein FIG. 36A shows an optical network with a ring configuration including a standby circuit, and FIG. 36B shows an optical network with a mesh configuration;

FIG 37 is a diagram showing the relationship of FIGs. 37A and 37B;

FIGs. 37A and 37B are block diagrams showing an internal configuration of a transmit/receive terminal of the 17th embodiment in accordance with the present invention;

5   FIG. 38 is a block diagram showing an internal configuration of an optical amplifying repeating system of FIG. 37;

FIG. 39 is a flowchart illustrating a procedure of fault detection and route control in an optical signal

10   monitoring system of the 17th embodiment in accordance with the present invention;

FIGs. 40A and 40B are schematic diagrams illustrating an initial stage of signal-to-noise ratio coefficient measuring algorithm of an 18th embodiment in accordance

15   with the present invention;

FIGs. 41A and 41B are schematic diagrams illustrating the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 40A and 40B in the 18th embodiment in accordance with the present invention;

20   FIGs. 42A and 42B are schematic diagrams illustrating the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 41A and 41B in the 18th embodiment in accordance with the present invention;

FIG. 43 is a schematic diagram illustrating the

25   signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 42A and 42B in the 18th embodiment in accordance with the present invention;

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FIGs. 44A and 44B are schematic diagrams illustrating an initial stage of signal-to-noise ratio coefficient measuring algorithm of a 19th embodiment in accordance with the present invention;

5   FIGs. 45A and 45B are schematic diagrams illustrating the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 44A and 44B in the 19th embodiment in accordance with the present invention;

FIGs. 46A and 46B are schematic diagrams illustrating

10   the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 45A and 45B in the 19th embodiment in accordance with the present invention;

FIG. 47 is a schematic diagram illustrating the signal-to-noise ratio coefficient measuring algorithm

15   following that of FIGs. 46A and 46B in the 19th embodiment in accordance with the present invention;

FIGs. 48A and 48B are schematic diagrams illustrating an initial stage of signal-to-noise ratio coefficient measuring algorithm of a 20th embodiment in accordance with

20   the present invention;

FIGs. 49A and 49B are schematic diagrams illustrating the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 48A and 48B in the 20th embodiment in accordance with the present invention;

25   FIGs. 50A and 50B are schematic diagrams illustrating the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 49A and 49B in the 20th embodiment

in accordance with the present invention;

FIG. 51 is a schematic diagram illustrating the signal-to-noise ratio coefficient measuring algorithm following that of FIGs. 50A and 50B in the 20th embodiment in accordance with the present invention.

FIG. 52 is a graph illustrating the relationship between the standard deviation for eight repeated evaluation points (vertical axis) and the total number of samplings used for the average Q factor evaluation (horizontal axis) of a B bit/s NRZ optical signal of a 21st embodiment in accordance with the present invention;

FIG. 53A and 53B are graphs illustrating the standard deviation and the average value for eight repeated evaluation points (vertical axis) depending on the sampling resolution (horizontal axis), respectively of a 21st embodiment in accordance with the present invention;

FIG. 54A is a graph illustrating the dependence of the average Q factor on the Q factor of a B bit/s NRZ optical signal of a 21st embodiment in accordance with the present invention; and

FIG. 54B is a graph illustrating the dependence of the linear fitting slope of the average Q and Q relationship on the optical band-pass filter.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The optical wavelength division multiplexed signal

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monitoring apparatus of the embodiments according to the present invention will now be described with reference to the accompanying drawings.

5   (First Embodiment)

FIG. 7 shows a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a first embodiment in accordance with the present invention. A wavelength division demultiplexer 11 carries out the

10   wavelength division demultiplexing of an optical wavelength division multiplexed signal consisting of N optical signals with a bit rate f_0 (bits/s) that undergo the wavelength multiplexing. Subsequently, N photoelectric converters 15 convert them into N channel

15   electric signals to be supplied to an electric signal processor 19. As will be described later, the present embodiment is an example in which the electric signal processor 19 stores the N channel electric signals for a predetermined time period, and processes them by reading

20   them sequentially, thereby reducing the electric signal processing process to a single system.

The electric signal processor 19 comprises N input ports for accepting the N channel electric signals and N voltage holding sections 192, and a sequential read section

25   193, a clock distributing section 194 and a data processing section 195. The voltage holding sections 192 carry out the analog-to-digital conversion of the input electric

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signals, hold the digital signal voltages for a time period, and output them in response to an external trigger signal. The sequential read section 193, operating in synchronism with the clock signal delivered from the clock distributing

5   section 194, reads the digital signal voltages sequentially from the voltage holding sections 192 by supplying them, which are associated with channel 1 to N, with a trigger signal, and delivers the channel 1 to N data to the data processing section 195 in the time-series

10   fashion. The data processing section 195 obtains the optical signal intensity distribution from the N-channel digital signal voltages, and evaluates the optical signal quality parameter of each of the N-channels from the optical signal intensity distribution. Although the

15   detail of an evaluation method of the quality evaluation parameter will be described later, a known quality evaluation parameter evaluation method is applicable such as that disclosed in the reference material [2].

20   (Second Embodiment)

FIG. 8 shows a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a second embodiment in accordance with the present invention. The wavelength division demultiplexer 11 carries out the

25   wavelength division demultiplexing of the optical wavelength division multiplexed signal consisting of N optical signals with a bit rate f_0 (bits/s) that undergo

the wavelength multiplexing. Subsequently, the N
photoelectric converters 15 convert them into N channel
electric signals to be supplied to an electric signal
processor 19. As will be described later, the present
5   embodiment is an example in which a switching section 191
in the electric signal processor 19 sequentially switches
connection of the N channel analog electric signals,
thereby reducing the electric signal processing process
to a single system.

10   The electric signal processor 19 comprises N input
ports for accepting the N channel electric signals and the
single switching section 191, and a voltage holding section
192, a clock distributing section 194 and a data processing
section 195. The switching section 191 switches the
15   connection between the N input ports and the single voltage
holding section 192 sequentially from channel 1 to N in
synchronism with the clock signal delivered from the clock
distributing section 194. Here, the time period of the
switching can be adjusted to any desired value. Here, the
20   time period is approximately equal to the time a particular
channel is connected to the voltage holder. The voltage
holding section 192 carries out the analog-to-digital
conversion of the input electric signal, holds the digital
signal voltage for a time period, and outputs it in response
25   to the external trigger signal delivered by the clock
distributing section 194. The data processing section 195
obtains the optical signal intensity distribution from the

N-channel digital signal voltages, and evaluates the optical signal quality parameter of each of the N-channels from the optical signal intensity distribution. Although the detail of the evaluation method of the quality

5 evaluation parameter will be described later, a known quality evaluation parameter evaluation method is applicable such as that disclosed in the reference material [2].

10 (Third Embodiment)

FIG. 9 shows a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a third embodiment in accordance with the present invention. A wavelength selecting section 42 selects one of N optical

15 signals with a bit rate f_0 (bits/s) that are wavelength multiplexed into the optical wavelength division multiplexed signal, and the selected optical signal reaches the electric signal processor 19 as a single-channel electric signal through the single photoelectric

20 converter 15.

The electric signal processor 19 comprises one input port for accepting the one-channel electric signal, a voltage holding section 192, a clock distributing section 194 and a data processing section 195. The voltage holding

25 section 192 carries out the analog-to-digital conversion of the input electric signal, holds the digital signal voltage for a time period, and outputs it in response to

the external trigger signal delivered by the clock

distributing section 194. The data processing section 195

obtains the optical signal intensity distribution from the

N-channel digital signal voltages, and evaluates the

5   optical signal quality parameter of each of the N-channels

from the optical signal intensity distribution. Although

the detail of the evaluation method of the quality

evaluation parameter will be described later, a known

quality evaluation parameter evaluation method is

10   applicable such as that disclosed in the reference material

[2].

(Fourth Embodiment)

FIG. 10 shows a configuration of an optical

15   wavelength division multiplexed signal monitoring

apparatus of a fourth embodiment in accordance with the

present invention. The optical wavelength division

multiplexed signal monitoring apparatus of the present

embodiment comprises the optical wavelength division

20   demultiplexer 11, N photoelectric converters 15, the

sampling clock generator 17 and the electric signal

processor 19. The optical wavelength division

demultiplexer 11 carries out the optical wavelength

division demultiplexing of the optical wavelength division

25   multiplexed signal consisting of N optical signals with

a bit rate f_0 (bits/s) that undergo the wavelength

multiplexing, where N is an integer greater than one. The

N photoelectric converters 15 receive the N-channel optical wavelength division demultiplexed singals demultiplexed by the optical wavelength division demultiplexer 11, and convert them into the electric intensity modulated signals. The sampling clock generator 17 generates the sampling clock signal with the repetition frequency of f_1 (Hz) (f_1 = $(n/m)f_0$ + a, where n and m are a natural number, and a is an offset frequency). The electric signal processor 19 samples the N-channel electric intensity modulated signals output from the N photoelectric converters 15 by the sampling clock signal generated by the sampling clock generator 17, obtains the optical signal intensity distribution from the sampled signals, and evaluates the optical signal quality parameter of each of the N channels from the optical signal intensity distribution.

In the foregoing configuration, the optical wavelength division demultiplexer 11 and photoelectric converters 15 convert the optical signals with the bit rate f_0 (bits/s) into the electric intensity modulated signals. The electric signal processor 19, which uses the electric sampling method, measures the optical signal intensity distribution by sampling the intensity of the electric intensity modulated signal using the sampling clock signal with a frequency f_1 (Hz) (f_1 = $(N/M)f_0$ + a, where a is an offset frequency), which is generated by the sampling clock generator 17.

For the measurement of the optical signal intensity distribution by the electric sampling method, a commercially available electric sampling apparatus can be used. In addition, although the detail of the evaluation method of the quality evaluation parameter will be described later, the known quality evaluation parameter evaluation method disclosed in the foregoing reference material [2] is applicable.

The present embodiment extends the monitoring method, which monitors by the single circuit the optical signal quality degradation such as the SNR degradation and waveform distortion regardless of the signal bit rate, signal format and modulation method, to the N wavelength optical wavelength division multiplexed signal by using the optical wavelength division demultiplexer 11. Thus, it can monitor the optical signal quality of the optical wavelength division multiplexed signal. The method of evaluating the optical signal quality parameter from the optical signal intensity distribution has no wavelength dependence in the electric signal processing, and can achieve the processing in the time-series fashion because of its statistical method. Therefore, it can be implemented by using only one electric signal processor 19, and hence serve to reduce the size and cost of the apparatus.

In addition, since the present embodiment utilizes the electric sampling, the size of the apparatus can be

made smaller than that using an optical sampling method.
However, the optical signal bit rate achieved is limited
by the bandwidth of the photoelectric converters 15.

5   (Fifth Embodiment)

FIG. 11 shows a configuration of an optical
wavelength division multiplexed signal monitoring
apparatus of a fifth embodiment in accordance with the
present invention. The optical wavelength division
10   multiplexed signal monitoring apparatus of the present
embodiment comprises the optical wavelength division
demultiplexer 11, an optical sampling pulse train
generator 21, an optical sampling pulse train splitter 22,
N optical multiplexers 23, where N is an integer greater
15   than one, N nonlinear optical media 24, N optical splitters
25, N photoelectric converters 15, and an electric signal
processor 26.

The optical wavelength division demultiplexer 11
carries out the optical wavelength division demultiplexing
20   of the optical wavelength division multiplexed signal
consisting of the N optical signals of the bit rate f_0
(bits/s) which are wavelength multiplexed, where N is an
integer greater than one. The optical sampling pulse
train generator 21 generates the optical sampling pulse
25   train whose repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0$
+ a, where n and m are a natural number, and a is an offset
frequency), and whose pulse width is sufficiently narrower

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than the time slot of the optical signal with the bit rate f_0 (bits/s). The optical sampling pulse train splitter 22 splits the optical sampling pulse train generated by the optical sampling pulse train generator 21 into N sequences.

5   The N optical multiplexers 23 combines one of the N-channel optical wavelength division demultiplexed singals output from the optical wavelength division demultiplexer 11 with one of the N sequence optical sampling pulse trains output from the optical sampling pulse train splitter 22.

10   The N nonlinear optical media 24 induces the nonlinear interaction between the optical wavelength division demultiplexed singal and the optical sampling pulse train combined by the optical multiplexer 23. The N optical splitters 25 each split the cross-correlation

15   optical signal, which is produced by the nonlinear interaction in the nonlinear optical medium 24, from the optical wavelength division multiplexed signal and the optical sampling pulse train. The N photoelectric converters 15 each receive one of the N-channel cross-

20   correlation optical signals from the corresponding optical splitter 25, and convert it to the electric intensity modulated signal.

The electric signal processor 26 obtains the optical signal intensity distribution from the N-channel electric

25   intensity modulated signals output from the photoelectric converter 15, and evaluates for each of the N-channel the optical signal quality parameter from the optical signal

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intensity distribution. Although the detail of the
evaluation method of the quality evaluation parameter will
be described later, the known quality evaluation parameter
evaluation method is applicable which is disclosed in the
5   reference material [2].

With the foregoing configuration, the present
embodiment utilizes the optical sampling methode for
measuring the intensity distribution of the optical signal.
Namely, the optical wavelength division demultiplexer 11,
10   optical sampling pulse train generator 21, optical
sampling pulse train splitter 22, N optical multiplexers
23 (N is an integer greater than one), N nonlinear optical
media 24, and N optical splitters 25, utilizing the optical
signal with the bit rate f_0 (bits/s), and the optical
15   sampling pulse train whose repetition frequency is f_1 (Hz)
($f_1 = (N/M)f_0 + a$, a is an offset frequency) and whose pulse
width is sufficiently narrower than the time slot of the
optical signal, generate the cross-correlation signals
with the optical frequency different from those of the two
20   optical signals. Then, after the N photoelectric
converters 15 carry out the optoelectric conversion of the
optical cross-correlation signals, the electric signal
processor 26 performs electric signal processing for
measuring the intensity distribution of the optical
25   signal.

The foregoing optical signal intensity distribution
measurement using the optical sampling method can utilize

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the known technique such as the optical sampling of the reference material [3] (reference material [3]: Takara Hidehiko, et al. "Ultra-fast Optical Waveform Measuring Method by Optical Sampling Using Sum Frequency Optical

5   Signal Generation", The Journal of the Institute of Electronics, Information and Communication Engineers of Japan, B-1, vol. J75-B-1, No.5, pp.372-380, 1992).

In addition, the cross-correlation signal can be obtained by utilizing the second-order harmonic optical

10   signal generation, sum frequency optical signal generation, difference frequency optical signal generation, or four wave mixing.   Incidentally, it is enough for the nonlinear optical media 24 to handle the wavelengths of the incident optical signals, and hence a wide wavelength range is not

15   required of them.

As the foregoing fourth embodiment, the present embodiment extends the monitoring method, which monitors by the single circuit the optical signal quality degradation such as the SNR degradation and waveform

20   distortion regardless of the signal bit rate, signal format and modulation method, to the N wavelength optical wavelength division multiplexed signal by using the optical wavelength division demultiplexer 11.   Thus, it can monitor the optical signal quality of the optical

25   wavelength division multiplexed signal.   Since the electric signal processing method of evaluating the optical signal quality parameter from the optical signal

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intensity distribution has no wavelength dependence, it is implemented by only one electric signal processor 26, thereby being able to reduce the size and cost of the apparatus.

5   In addition, since the present embodiment uses the optical sampling, the optical signal bit rate is not limited by the bandwidth of the photoelectric converters 15. Accordingly, the present embodiment can handle a wider range of the optical signal bit rate than that of
10   the foregoing fourth embodiment using the electric sampling. Furthermore, since the bandwidth of the opto-electric conversions is determined by f_1 that can be set at a small value even if the signal bit rate f_0 is large, the bandwidth required by the photoelectric converters and
15   the following electric processing section can be made small. This makes it possible to reduce the cost of the portion that executes the electric processing.

    (Sixth Embodiment)

20   FIG. 12 shows a configuration of an optical wavelength division multiplexed signal monitoring apparatus of a sixth embodiment in accordance with the present invention. The optical wavelength division multiplexed signal monitoring apparatus of the present
25   embodiment comprises the optical wavelength division demultiplexer 11, N optical gating sections 171, N photoelectric converters 15, a sampling clock generator

17, and an electric signal processor 19. The optical
wavelength division demultiplexer 11 carries out the
optical wavelength division demultiplexing of the optical
wavelength division multiplexed signal consisting of the

5   N optical signals of the bit rate f_0 (bits/s) which are
wavelength multiplexed, where N is an integer greater than
one. The sampling clock generator 17 generates the
sampling clock signal with a repetition frequency f_1 (Hz)
($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and

10   a is an offset frequency).

        The optical gating sections 171, each of which is
provided for one of the channels, sample the intensity of
the N-channel optical wavelength division demultiplexed
singals with the bit rate f_0 (bits/s), which are

15   demultiplexed by the optical wavelength division
demultiplexer 11, using the sampling clock signal
generated by the sampling clock generator 17. The N
photoelectric converters 15 receive the optical signals
sampled by the optical gating sections 171 for respective

20   channels, and convert them to the electric intensity
modulated signals. The electric signal processor 19
measures the optical signal intensity distribution by
carrying out the signal processing of the N-channel
electric intensity modulated signals supplied from the N

25   photoelectric converters 15, and evaluates for each of the
N channels the optical signal quality parameter from the
optical signal intensity distribution.

More specifically, the optical gating sections 171 sample the signal light with a gate width less than the time slot (= $1/f_0$) with the repetition frequency f_1 (Hz). In parallel with this, the electric signal processor 19

5   stores the sampled electric signals the photoelectric converters 15 produce in synchronism with the sampling of the optical gating sections 171, obtains the optical signal intensity distribution from the sampled electric signals, and checks the quality of the optical signal by calculating

10   mean value levels and standard deviations at "level 1" and "level 0" within a certain mean time from the distribution.

Thus, the optical signal quality monitor with the configuration employs an electric-optical sampling method that samples the optical signal by the electric signal of

15   the sampling clock signal, which differs from the conventional optical signal quality monitor that utilizes an optical-optical sampling method or electric-electric sampling method. The evaluation method of the quality evaluation parameter is the same as that disclosed in the

20   referense material [2].

FIG. 13 is a diagram illustrating a level setting method of light intensity histograms the electric signal processor 19 measures which is installed in the optical signal quality monitor in accordance with the present

25   invention. Receiving the electric signals the photoelectric converters 15 output by converting the optical signals, the electric signal processor 19 detects

and analyzes the peak value of the electric signals, and measures the light intensity histograms as illustrated in FIG. 13. Among the sampled points constituting the light intensity histograms, the electric signal processor 19

5 makes a decision of "level 1" point group as those points that are higher than a predetermined threshold level L_{th1}, and "level 0" point group as those points that are lower than a predetermined threshold level L_{th0}. Then, it evaluates the quality of the optical signal by calculating

10 the mean value levels and standard deviations (σ_1 and σ_0) at the "level 1" and "level 0" within the certain mean time.

FIG. 14 is a block diagram illustrating a first configuration of the optical gating section 171 of the

15 optical signal quality monitor in accordance with the present invention. The optical gating section 171 comprises a comb generator 1711, bias-Tee 1712, DC power supply 1713, electroabsorption optical modulator 1714.

The comb generator 1711 generates the driving signal

20 of the electroabsorption optical modulator 1714 by converting sinusoidal sampling clock signal with a frequency f_1 into an electric pulse train with a repetition frequency f_1 and small duty, and by superimposing the electric pulse train and the DC voltage fed from the DC

25 power supply 1713 by the bias-Tee 1712. The gate width is adjustable by setting the peak value of the electric pulses and the DC voltage appropriately. For example, as

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with the sampling clock signal with a frequency 1 GHz, a gate width of about 8 ps can be achieved. The gate width is narrower than the time resolution of about 10 ps achieved by a combination with a commercially available

5 photoelectric converter with an electric sampling apparatus, thereby making it possible to handle the optical signal with a bit rate of 40 Gbits/s.

FIG. 15 is a block diagram illustrating a second configuration of the optical gating section 172 of the

10 optical signal quality monitor in accordance with the present invention. The optical gating section 172 comprises a comb generator 1721, a bias-Tee 1722, a DC power supply 1723, a phase adjuster 1724, a first electroabsorption optical modulator 1725 and a second

15 electroabsorption optical modulator 1726.

In the optical gating section 172 with such a configuration, the electric signal from the bias-Tee 1722 is split into two portions, which are supplied to the first electroabsorption optical modulator 1725 and second

20 electroabsorption optical modulator 1726, respectively. The two electroabsorption optical modulators 1725 and 1726 sample the optical signals alternately. By adjusting the timing the first electroabsorption optical modulator 1725 and the second electroabsorption optical modulator 1726

25 sample the optical signals, the sampling with a gate width narrower than the one stage optical gating section 171 as illustrated in FIG. 14 is implemented. For example, as

for the sampling clock signal with a frequency of 1 GHz,
the gate width of about 5-6 ps is achieved, which makes
it possible to monitor the quality of the optical signal
with a bit rate of about 70-80 Gbits/s.

5   Incidentally, in the two-stage optical gating
section as shown FIG. 15, since the loss of the
electroabsorption optical modulators doubles, the level
of the sampled optical signal passing through the
modulators is reduced. In such a case where
10 characteristic degradation in the signal quality
monitoring takes place, an optical amplifier 1727 such as
a rare-earth-doped optical fiber amplifier and
semiconductor optical amplifier can be interposed between
the first electroabsorption optical modulator 1725 and the
15 second electroabsorption optical modulator 1726, or before
or after these electroabsorption optical modulators 1725
and 1726.

(Seventh Embodiment)

          FIG. 16 shows a configuration of an optical
20 wavelength division multiplexed signal monitoring
apparatus of a seventh embodiment in accordance with the
present invention. The optical wavelength division
multiplexed signal monitoring apparatus of the present
embodiment comprises an optical gating section 171, a
25 sampling clock generator 17, an optical wavelength
division demultiplexer 11, N photoelectric converters 15,
and an electric signal processor 19. The sampling clock

generator 17 generates a sampling clock signal whose
repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where
n and m are a natural number, and a is an offset frequency),
and whose pulse width is sufficiently narrower than the

5   time slot of the optical signal with the bit rate f_0 (bits/s).
Although the operation of the optical gating section 171
is the same as that of the foregoing sixth embodiment, the
present embodiment is characterized in that the optical
wavelength division multiplexed signal including N channel

10   optical signals, which passes through the optical gating
section 171 before the optical wavelength division
demultiplexing, is supplied to the optical wavelength
division demultiplexer 11 that carries out the optical
wavelength division demultiplexing.

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(Eighth Embodiment)

FIG. 17 shows a configuration of an optical
wavelength division multiplexed signal monitoring
apparatus of an eighth embodiment in accordance with the

20   present invention. The optical wavelength division
multiplexed signal monitoring apparatus of the present
embodiment comprises an optical sampling pulse train
generator 21, an optical multiplexer 31, a nonlinear
optical medium 24, an optical wavelength division

25   demultiplexer 11, N photoelectric converters 15, and an
electric signal processor 26.

The optical sampling pulse train generator 21

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generates an optical sampling pulse train whose repetition
frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are
a natural number, and a is an offset frequency), and whose
pulse width is sufficiently narrower than the time slot

5   of the optical signal with the bit rate f_0 (bits/s). The
optical multiplexer 31 combines the optical sampling pulse
train generated by the optical sampling pulse train
generator 21 with the optical wavelength division
multiplexed signal consisting of N optical signals with

10   the bit rate f_0 (bits/s) which are wavelength multiplexed,
where N is an integer greater than one. The nonlinear
optical medium 24 induces the nonlinear interaction
between the optical wavelength division multiplexed signal
output from the optical multiplexer 31 and the optical

15   sampling pulse train. The optical wavelength division
demultiplexer 11 carries out the wavelength division
demultiplexing of the cross-correlation optical signal
caused by the nonlinear interaction in the nonlinear
optical medium 24 into N-channels.

20   The N photoelectric converters 15 receive the N-
channel cross-correlation optical signals from the optical
wavelength division demultiplexer 11, and convert them
into the N-channel electric intensity modulated signals.
The electric signal processor 26 obtains the optical signal

25   intensity distribution from the N-channel electric
intensity modulated signals output from the photoelectric
converters 15, and evaluates for each of the N channels

the optical signal quality parameter from the optical signal intensity distribution. Although the detail of the evaluation method of the quality evaluation parameter will be described later, a known quality evaluation parameter

5   evaluation method such as that disclosed in the reference material [2] is applicable.

In the configuration, the optical sampling pulse train generator 21, optical multiplexer 31, nonlinear optical medium 24 and optical wavelength division

10   demultiplexer 11, using the optical signal with the bit rate f_0 (bits/s) and the optical sampling pulse train whose repetition frequency is f_1 (Hz) ($f_1 = (N/M)f_0 + a$, a is an offset frequency) and whose pulse width is sufficiently narrower than the time slot of the optical signal,

15   generates the cross-correlation signals with an optical frequency different from those of the two optical signals used.

Subsequently, after the N photoelectric converters 15 carry out the opto-electric conversion of the

20   cross-correlation optical signals, the electric signal processor 26 executes the optical sampling method of measuring the intensity distribution of the optical signals by performing the electric signal processing. The optical signal intensity distribution measurement by the

25   optical sampling method can employ the optical sampling disclosed in the foregoing reference material [3]. The cross-correlation signals can be obtained by utilizing the

second-order harmonic optical signal generation, sum frequency optical signal generation, difference frequency optical signal generation, or four wave mixing.

The present embodiment can reduce the optical combining means, nonlinear optical medium and optical spitting means into one system by employing as the nonlinear optical medium 11 the nonlinear optical medium with large generation efficiency of the cross-correlation signals over a wide bandwidth, thereby making it possible to reduce the size and cost of the entire circuit.

In addition, the present embodiment can monitor the optical signal quality degradation such as SNR degradation and waveform distortion by a single circuit regardless of the bit rate, signal format and modulation method of the target optical wavelength division multiplexed signal to be measured. Furthermore, the present embodiment can use a wider range of the optical signal bit rate than the fourth embodiment using the electric sampling. Moreover, although the nonlinear optical medium 11 must be applicable to all the optical signal wavelengths, that is, must possess a wide wavelength range, since the number of the optical multiplexer 31 and nonlinear optical medium 24 is one, the present embodiment has a simpler configuration than that of the first or fifth embodiment.

(Ninth Embodiment)

FIG. 18 shows a configuration of an optical

wavelength division multiplexed signal monitoring apparatus of a ninth embodiment in accordance with the present invention. The optical wavelength division multiplexed signal monitoring apparatus of the present

5   embodiment comprises an optical wavelength selecting section 42, a selection wavelength control section 41, a single photoelectric converter 15, a sampling clock generator 17 and an electric signal processor 19.

The optical wavelength selecting section 42 selects

10   any one of the channels from the optical wavelength division multiplexed signal consisting of N optical signals with the bit rate f_0 (bits/s), which are wavelength multiplexed, where N is an integer greater than one, and carries out the optical wavelength division demultiplexing.

15   The selection wavelength control section 41 controls the wavelength the optical wavelength selecting section 42 selects. The photoelectric converter 15 receives the one-channel optical wavelength division demultiplexed singal the optical wavelength selecting section 42 selects

20   and demultiplexes, and converts it into the electric intensity modulated signal.

The sampling clock generator 17 generates the sampling clock signal whose repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and

25   a is an offset frequency). The electric signal processor 19 samples the one-channel electric intensity modulated signal output from the photoelectric converter 15 by the

sampling clock signal supplied from the sampling clock
generator 17, obtains the optical signal intensity
distribution from the sampled signal, and evaluates the
optical signal quality parameter from the optical signal

5   intensity distribution. Although the detail of the
evaluation method of the quality evaluation parameter will
be described later, the known quality evaluation parameter
evaluation method disclosed in the reference material [2]
is applicable.

10   In the configuration, the optical wavelength
selecting section 42 demultiplexes any one channel from
the optical wavelength division multiplexed signal with
the bit rate f_0 (bits/s). The photoelectric converter 15
receives the one-channel optical wavelength division

15   demultiplexed singal, and converts it into an electric
intensity modulated signal. The electric signal
processor 19 employs the electric sampling method that
measures the optical signal intensity distribution by
sampling the intensity of the electric intensity modulated

20   signal using the clock signal of the frequency f_1 (Hz) (f_1
= (N/M)f_0 + a, where a is an offset frequency) supplied
from the sampling clock generator 17. The optical signal
intensity distribution measurement by the electric
sampling method can use a commercially available electric

25   sampling apparatus.

        The present embodiment implements the evaluation of
the optical wavelength division multiplexed signal by

performing the wavelength selection in the wavelength demultiplexing process using the optical wavelength selecting section 42 and selection wavelength control section 41 before the electric signal processor 19, and

5   by sequentially evaluating the N wavelengths of the optical wavelength division multiplexed signal in the time-series fashion, thereby implementing the evaluation. As a result, the input to the electric signal processing section 19 can be composed of one channel, and the electric signal

10   processor 19 can be composed of one buffer and one reading circuit, thereby being able to simplify the apparatus.

The present embodiment can monitor by a single circuit the optical signal quality degradation such as SNR degradation and waveform distortion regardless of the bit

15   rate, signal format and modulation method of the target optical wavelength division multiplexed signal to be measured. In addition, the method of evaluating the optical signal quality parameter from the optical signal intensity distribution in the present embodiment has no

20   wavelength dependence in the electric signal processing, and is a statistical method. Thus, it can carry out the processing in the time-series fashion. As a result, the electric signal processor 19 can be composed of one system, thereby being able to reduce the size and cost of the

25   apparatus.

In addition, since the present embodiment employs the electric sampling, it can reduce the size of the apparatus

as compared with the apparatus using the optical sampling
method. However, the applicable optical signal bit rate
is limited by the bandwidth of the photoelectric converter
15. Since the present embodiment comprises only one

5   photoelectric converter 15, it can reduce its size and cost
in its entirety.

(10th Embodiment)

FIG. 19 shows a configuration of an optical
wavelength division multiplexed signal monitoring

10   apparatus of a 10th embodiment in accordance with the
present invention. The optical wavelength division
multiplexed signal monitoring apparatus of the present
embodiment comprises an optical wavelength selecting
section 42, a selection wavelength control section 41, a

15   sampling clock generator 17, a single optical gating
section 171, a single photoelectric converter 15, and an
electric signal processor 26.

The present embodiment is characterized by utilizing
the optical gating section 171 and sampling clock generator

20   17, which are described in the fifth embodiment, instead
of an optical sampling section (nonlinear optical medium
24, optical sampling pulse train generator 21 and optical
splitter 25) which is shown in Fig. 20 in connection with
the following 11th embodiment. As described below, the

25   present embodiment carries out the optical sampling of the
WDM signal by an optical clock signal, followed by the
wavelength division demultiplexing, and the N-parallel

opto-electric conversion, thereby implementing the single electric signal processor. Using the optical sampling all the way to the electric signal processing, the present embodiment can reduce the electric bandwidth of the

5   electric signal processing.

The optical wavelength selecting section 42 selects any one of the channels from the optical wavelength division multiplexed signal consisting of N optical signals with the bit rate f_0 (bits/s), which are wavelength

10   multiplexed, where N is an integer greater than one, and carries out the optical wavelength division demultiplexing. The selection wavelength control section 41 controls the wavelength the optical wavelength selecting section 42 selects. The sampling clock generator 17 generates the

15   sampling clock signal whose repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency). The optical gating section 171 samples the intensity of the one-channel optical wavelength division demultiplexed singal, which is

20   selected and demultiplexed by the optical wavelength selecting section 42, by using the sampling clock signal the sampling clock generator 17 outputs.

The photoelectric converter 15 receives the optical gate signal (repetition frequency of f_1 (bits/s) $\times$ one

25   wavelength) the optical gating section 171 outputs, and converts it into an electric intensity modulated signal. The electric signal processor 26 obtains the optical signal

intensity distribution from the one-channel electric
intensity modulated signal output from the photoelectric
converter 15, and evaluates the optical signal quality
parameter from the optical signal intensity distribution.

5   Although the detail of the evaluation method of the quality
evaluation parameter will be described later, the known
quality evaluation parameter evaluation method disclosed
in the reference material [2] is applicable.

10   (11th Embodiment)

        FIG. 20 shows a configuration of an optical
wavelength division multiplexed signal monitoring
apparatus of an 11th embodiment in accordance with the
present invention. The optical wavelength division

15   multiplexed signal monitoring apparatus of the present
embodiment comprises an optical wavelength selecting
section 42, a selection wavelength control section 41, an
optical sampling pulse train generator 21, an optical
multiplexer 31, a single nonlinear optical medium 24, a

20   single optical splitter 25, a single photoelectric
converter 15, and an electric signal processor 26.

        The optical wavelength selecting section 42 selects
any one of the channels from the optical wavelength
division multiplexed signal consisting of N optical

25   signals with the bit rate f_0 (bits/s), which are wavelength
multiplexed, where N is an integer greater than one, and
carries out the optical wavelength division demultiplexing.

The selection wavelength control section 41 controls the wavelength the optical wavelength selecting section 42 selects. The optical sampling pulse train generator 21 generates the optical sampling pulse train whose

5   repetition frequency is f_1 (Hz) ($f_1 = (n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency), and whose pulse width is sufficiently narrower than the time slot of the optical signal with the bit rate f_0 (bits/s). The optical multiplexer 31 combines one-channel optical

10 wavelength division demultiplexed singal selected and demultiplexed by the optical wavelength selecting section 42 with the optical sampling pulse train output from the optical sampling pulse train generator 21.

The nonlinear optical medium 24 induces the nonlinear

15 interaction between the optical wavelength division demultiplexed singal and the optical sampling pulse train combined by the optical multiplexer 31. The optical splitter 25 demultiplexes the cross-correlation optical signal, which is produced by the nonlinear interaction in

20 the nonlinear optical medium 24, from the optical wavelength division demultiplexed singal and the optical sampling pulse train.

The photoelectric converter 15 receives the one-channel cross-correlation optical signal the optical

25 splitter 25 outputs, and converts it to the electric intensity modulated signal. The electric signal processor 26 obtains the optical signal intensity

distribution from the one-channel electric intensity
modulated signal output from the photoelectric converter
15, and evaluates the optical signal quality parameter from
the optical signal intensity distribution. Although the
5   detail of the evaluation method of the quality evaluation
parameter will be described later, the known quality
evaluation parameter evaluation method disclosed in the
reference material [2].

In the configuration, the optical wavelength
10   selecting section 42, selection wavelength control section
41, optical sampling pulse train generator 21, optical
multiplexer 31, single nonlinear optical medium 24, and
single optical splitter 25, using the optical signal with
the bit rate f_0 (bits/s) and the optical sampling pulse
15   train whose repetition frequency is f_1 (Hz) (f_1 = (N/M)f_0
+ a, a is an offset frequency) and whose pulse width is
sufficiently narrower than the time slot of the optical
signal, generates the cross-correlation signals with an
optical frequency different from those of the two optical
20   signals used.

Subsequently, after the photoelectric converter 15
carries out the opto-electric conversion of the cross-
correlation optical signals, the electric signal processor
26 executes the optical sampling method of measuring the
25   intensity distribution of the optical signals by
performing the electric signal processing. The optical
signal intensity distribution measurement by the optical

sampling method can employ the optical sampling disclosed in the foregoing reference material [3]. The cross-correlation signals can be obtained by utilizing the second-order harmonic optical signal generation, sum

5   frequency optical signal generation, difference frequency optical signal generation, or four wave mixing.

The present embodiment can monitor the optical signal quality degradation such as SNR degradation and waveform distortion by a single circuit regardless of the bit rate,

10   signal format and modulation method of the target optical wavelength division multiplexed signal to be measured. Furthermore, the present embodiment implements the evaluation of the optical wavelength division multiplexed signal by sequentially evaluating the N wavelengths of the

15   optical wavelength division multiplexed signal in the time-series fashion using the optical wavelength selecting section 42 and selection wavelength control section 41. In addition, the present embodiment can reduce the optical multiplexer 31, nonlinear optical medium 24, optical

20   splitter 25, and photoelectric converter 15 into one system by employing as the nonlinear optical medium 24 the nonlinear optical medium with large generation efficiency of the cross-correlation signals over a wide bandwidth, and by monitoring the optical signal quality in the

25   time-series fashion by the wavelength selecting section 42, thereby making it possible to reduce the size and cost of the entire circuit.

In addition, the present embodiment can use a wider
range of the optical signal bit rate than the first and
ninth embodiments where the electric sampling is used.
Moreover, although the nonlinear optical medium 24 must
5   be applicable to all the optical signal wavelengths, that
is, must possess a wide wavelength range, since the number
of the optical multiplexer 31, nonlinear optical medium
24 and photoelectric converter 15 is one, the present
embodiment has a simpler configuration than that of the
10 fifth or eighth embodiment.

(12th Embodiment)

FIG. 21 shows a configuration of an optical
wavelength division multiplexed signal monitoring
15 apparatus of a 12th embodiment in accordance with the
present invention. The optical wavelength division
multiplexed signal monitoring apparatus of the present
embodiment comprises a sampling clock generator 17, a
single optical gating section 171, an optical wavelength
20 selecting section 42, a selection wavelength control
section 41, a single photoelectric converter 15, and an
electric signal processor 26. The present embodiment is
characterized in that the optical wavelength selecting
section 42 and selection wavelength control section 41 in
25 the foregoing 10th embodiment are placed after the optical
gating section 171.

The sampling clock generator 17 generates a sampling

clock signal whose repetition frequency is f_1 (Hz) (f_1 = $(n/m)f_0 + a$, where n and m are a natural number, and a is an offset frequency). The optical gating section 171 samples the intensity of the optical wavelength division multiplexed signal, which consists of N optical signals with the bit rate f_0 (bits/s) which are wavelength multiplexed, where N is an integer greater than one, by using the sampling clock signal fed from the sampling clock generator 17. The optical wavelength selecting section 42 selects any one of the channels from the gate signals with a repetition frequency f_1 (bits/s) $\times$ N wavelengths, which are output from the optical gating section 171, and carries out the optical wavelength division demultiplexing. The selection wavelength control section 41 controls the wavelength the optical wavelength selecting section 42 selects.

The photoelectric converter 15 receives the optical gate signal (repetition frequency of f_1 (bits/s) $\times$ one wavelength) the optical wavelength selecting section 42 outputs, and converts it into an electric intensity modulated signal. The electric signal processor 26 obtains the optical signal intensity distribution from the one-channel electric intensity modulated signal output from the photoelectric converter 15, and evaluates the optical signal quality parameter from the optical signal intensity distribution. Although the detail of the evaluation method of the quality evaluation parameter will

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be described later, the known quality evaluation parameter
evaluation method disclosed in the reference material [2]
is applicable.

5   (13th Embodiment)

FIG. 22 shows a configuration of an optical
wavelength division multiplexed signal monitoring
apparatus of a 13th embodiment in accordance with the
present invention. The optical wavelength division
10   multiplexed signal monitoring apparatus of the present
embodiment comprises an optical sampling pulse train
generator 21, an optical multiplexer 31, a single nonlinear
optical medium 24, an optical wavelength selecting section
42, a selection wavelength control section 41, a single
15   photoelectric converter 15, and an electric signal
processor 26. The present embodiment is characterized in
that it lacks the optical splitter of the 11th embodiment,
but comprises the optical wavelength selecting section 42
and selection wavelength control section 41 after the
20   nonlinear optical medium 24.

The optical sampling pulse train generator 21
generates an optical sampling pulse train whose repetition
frequency is f_1 (Hz) (f_1 = (n/m)f_0 + a, where n and m are
a natural number, and a is an offset frequency), and whose
25   pulse width is sufficiently narrower than the time slot
of the optical signal with the bit rate f_0 (bits/s). The
optical multiplexer 31 combines the optical sampling pulse

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train generated by the optical sampling pulse train generator 21 with the optical wavelength division multiplexed signal consisting of N optical signals with the bit rate f_0 (bits/s) which are wavelength multiplexed,

5 where N is an integer greater than one.

The nonlinear optical medium 24 induces the nonlinear interaction between the optical wavelength division multiplexed signal output from the optical multiplexer 31 and the optical sampling pulse train. The optical

10 wavelength selecting section 42 selects any one of the channels from the cross-correlation optical signal with the bit rate f_0 (bits/s) $\times$ N wavelengths which are output from the nonlinear optical medium 24, and carries out the optical wavelength division demultiplexing. The

15 selection wavelength control section 41 controls the wavelength to be selected by the optical wavelength selecting section 42.

The photoelectric converter 15 receives the one-channel cross-correlation optical signal the optical

20 wavelength selecting section 42 outputs, and converts it to the electric intensity modulated signal. The electric signal processor 26 obtains the optical signal intensity distribution from the one-channel electric intensity modulated signal output from the photoelectric converter

25 15, and evaluates the optical signal quality parameter from the optical signal intensity distribution. Although the detail of the evaluation method of the quality evaluation

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parameter will be described later, the known quality evaluation parameter evaluation method disclosed in the reference material [2] is applicable.

5   (14th Embodiment)

FIG. 23 shows, as a 14th embodiment in accordance with the present invention, a configuration of the optical sampling process section in the optical wavelength division multiplexed signal monitoring apparatus (the portion using the optical sampling pulse train generator 21, optical multiplexer 31, and nonlinear optical medium 24) in the eighth and 13th embodiments in accordance with the present invention. The configuration of the present embodiment is characterized by comprising a polarization control section 27 for controlling the polarization state of the optical wavelength division multiplexed signal in the optical sampling process. The polarization control section 27 controls the polarization state of all the channels of the optical wavelength division multiplexed signal in their entirety, and enables them to maintain fixed polarization relationships with the polarization state of the optical sampling pulse train output from the optical sampling pulse train generator 21.

When the optical sampling process section is composed of the optical gating section 171 and sampling clock generator 17 as shown in FIGs. 16 and 21 of the seventh and 12th embodiments, the polarization control section 27

is used in accordance with the polarization dependence of the electroabsorption optical modulator the optical gating section 171 employs. As the polarization control section 27, a single polarization controller is available. When

5 the polarization state of the individual channels of the optical wavelength division multiplexed signal differ from each other, two or more polarization controllers can be used in combination with the optical wavelength division demultiplexer, and optical wavelength division

10 multiplexer (not shown).

In contrast, only one polarization control section 27 is required when one channel (one wavelength) optical signal rather than the optical wavelength division multiplexed signal is launched into the nonlinear optical

15 medium as in the fourth and 11th embodiments as shown in FIGs. 10 and 20, or into the optical gating section 171 as in the fifth and 10th embodiments as shown in FIGs. 11 and 19.

20 (15th Embodiment)

FIG. 24 shows, as a 15th embodiment in accordance with the present invention, another configuration of the optical sampling process section in the optical wavelength division multiplexed signal monitoring apparatus (the

25 portion using the optical sampling pulse train generator 21, optical multiplexer 23 or 31, and nonlinear optical medium 24) in the fifth, eighth, 11th and 13th embodiments

in accordance with the present invention. The
configuration of the present embodiment is characterized
by comprising a wavelength dispersion controller 28 for
controlling the wavelength dispersion of the optical

5   wavelength division multiplexed signal in the optical
sampling process. The wavelength dispersion controller
28 controls the wavelength dispersion of all the channels
of the optical wavelength division multiplexed signal in
their entirety. As the wavelength dispersion controller

10   28, a single wavelength dispersion compensator is
available. Two or more wavelength dispersion
compensators can also be used in combination with the
optical wavelength division demultiplexer, and optical
wavelength division multiplexer (not shown). As the

15   wavelength dispersion compensator, an optical fiber, fiber
grating, or phase control type wavelength dispersion
compensator is applicable. In addition, only one
wavelength dispersion compensator is required when one
channel (one wavelength) optical signal rather than the

20   optical wavelength division multiplexed signal is launched
into the nonlinear optical medium as in the fourth and 11th
embodiments as shown in FIGs. 10 and 20.

       The following are concrete examples of the evaluation
method of the quality evaluation parameter, which is

25   carried by the electric signal processor 19 or 26 in the
foregoing first to 15th embodiments.

       (16th Embodiment)

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FIGs. 25A and 25B each show an optical network configuration of a 16th embodiment in accordance with the present invention: FIG. 25A shows a ring type optical network with a standby circuit, including optical ADM ring; and FIG. 25B shows a mesh type optical network.

Both the optical networks have a hierarchical structure including an optical layer that can accommodate electric signals with a variety of modulation methods, formats and bit rates such as a SONET/SDH frame, ATM cell or IP packet by converting them into an optical signal with a suitable carrier wavelength. Each optical node 102 constituting the optical network includes a pair of or multiple pairs of optical signal transmit terminal and optical signal receive terminal (transmit/receive terminal 104). An optical signal is terminated between the optical signal transmit terminal 104 of an optical node and the optical signal receive terminal 104 of another optical node. In addition, each optical signal termination forms an optical signal route independent of the modulation method, format and bit rate. The optical networks include the case where the optical signal passes through the optical node 102. Besides, it includes the case where optical amplifying repeating is carried out between the optical transmit/receive terminals 104.

As described later, the present invention carries out the optical signal monitoring in the optical signal receive terminal, transmits the monitor information to the optical

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signal transmit terminal using a control channel between the optical transmit/receive terminals, and performs optical signal switching in response to the monitor information.

5   FIGs. 26A and 26B show a configuration of the optical transmit/receive terminal 104 of the present embodiment. Receiving a signal from a higher level optical layer, the optical transmitter 204 of the optical signal transmit terminal 202 sends it to the transmission line 212 via the

10   route switching section 206. In the optical signal receive terminal 216, the optical branching circuit 218 extracts part of the input optical signal so that an optical signal monitoring section 220 monitors the optical signal by utilizing the optical signal extracted.

15   It is assumed here that the optical branching circuit 218 corresponds to the configuration without the electric signal processor 19 or 26 of FIGs. 10-20 of the foregoing fourth, fifth, seventh, eighth and 11th embodiments in accordance with the present invention. The optical signal

20   monitoring section 220 corresponds to the section in the electric signal processor 19 or 26 that carries out the quality evaluation parameter of the foregoing fourth, fifth, seventh, eighth and 11th embodiments in accordance with the present invention.

25   The optical signal monitoring section 220, which comprises a signal-to-noise ratio coefficient measuring section 222, an initial state storing section 224 and an

optical signal quality evaluating section 226, carries out the analog monitoring independent of the optical signal modulation method, format and bit rate. The signal-to-noise ratio coefficient measuring section 222 measures

5 the signal-to-noise ratio coefficient of the optical signal transmitted through the transmission line 212 between the optical signal transmit terminal 202 of an optical node and the optical signal receive terminal 216 of another optical node. The initial state storing

10 section 224 stores the signal-to-noise ratio coefficient the signal-to-noise ratio coefficient measuring section 222 measured at the system installation in a state without any fault. The optical signal quality evaluating section 226 compares the signal-to-noise ratio coefficient the

15 signal-to-noise ratio coefficient measuring section 222 measures at every predetermined time interval during the system operation with the signal-to-noise ratio coefficient the initial state storing section 224 stores at the system installation.

20 A control channel 214 for transmitting the monitor information from the optical signal monitoring section 220 to the optical signal transmit terminal 202 is installed besides the transmission line 212 between the optical signal receive terminal 216 of an optical node and the

25 optical signal transmit terminal 202 of another optical node. In addition, the optical signal receive terminal 216 and optical signal transmit terminal 202 comprise

monitor information control sections 228 and 210, respectively. The monitor information control sections 228 and 210 each recognize a network failure from the optical signal degradation or optical signal waveform distortion caused by a fault of the transmission line 212 in accordance with the optical signal quality evaluation by the optical signal quality evaluating section 226, and exchanges the monitor information including the recognized information via the control channel 214.

The optical signal transmit terminal 202 comprises the route switching section 206. The route switching section 206 carries out the route switching of the transmission line 212 in accordance with the monitor information fed from the monitor information control section 210, thereby recovering the network failure.

FIG. 27 illustrates the operation procedure of the route control by the optical signal monitoring system in the 16th embodiment in accordance with the present invention.

Step S1: The signal-to-noise ratio coefficient measuring section 222 measures the signal-to-noise ratio coefficient at the system installation in a state without any failure.

Step S2: The initial state storing section 224 stores the signal-to-noise ratio coefficient measured at Step S1.

Step S3: The signal-to-noise ratio coefficient measuring section 222 measures the signal-to-noise ratio

coefficient at the predetermined time intervals after starting the system operation.

Step S4: The optical signal quality evaluating section 226 compares the signal-to-noise ratio coefficient with that of the initial state storing section 224 every time it is measured.

Step S5: The optical signal quality evaluating section 226 supplies the monitor information control section 228 with the variations in the signal-to-noise ratio coefficient from the initial state as the monitor information. When it recognizes from the degree of variations in the signal-to-noise ratio coefficient that a failure takes place, it also supplies the monitor information control section 228 with warning information indicating that the route switching is required as the monitor information.

Step S6: The monitor information control section 228 transmits the monitor information to the monitor information control section 210 in the optical signal transmit terminal 202 via the control channel 214.

Step S7: The monitor information control section 210 of the optical signal transmit terminal 202 supplies the route switching section 206 with the information that the route switching is needed in response to the monitor information, if necessary.

Step S8: The route switching section 206 carries out the route switching of the transmission line 212 in

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accordance with the instruction of the monitor information control section 210.

As the signal-to-noise ratio coefficient measuring section 222, it is possible to use the optical signal
5 quality monitoring described in the reference material [2]. It does not require receiving systems corresponding to the bit rate, signal format and modulation method (that is, the clock extracting circuit, receiving circuit, frame detection circuit, and error detection circuit consisting
10 of a parity check circuit or comparing circuit), and can handle signals with any bit rate, signal format and modulation method by a single receiving system.

FIGs. 28 and 29 each show a configuration of the signal-to-noise ratio coefficient measuring section 222
15 utilizing the optical signal quality monitoring: FIG. 28 shows the configuration using an electrical sampling oscilloscope 404; and FIG. 29 shows the configuration using the optical sampling oscilloscope 414.

In the configuration of FIG. 28 using the electrical
20 sampling oscilloscope 404, a photoelectric converter 402 converts an optical intensity modulation signal with the bit rate f_0 (bits/s) into an electric intensity modulated signal; an electrical sampling oscilloscope 404 samples the intensity of the electric intensity modulated signal
25 at the clock signal frequency f_1 (Hz) ($f_1 = (N/M)f_0 + a$, where N and M are an integer, and a is an offset frequency) to obtain the signal intensity distribution in a fixed time

period; and a signal processor 406 carries out the signal-to-noise ratio coefficient evaluation. The signal processor 406 comprises a histogram evaluating section 408 and a signal-to-noise ratio coefficient evaluating section

5   410. The histogram evaluating section 408 obtains the amplitude histogram from the signal intensity distribution the electrical sampling oscilloscope 404 produces. The signal-to-noise ratio coefficient evaluating section 410 calculates from the amplitude histogram the distributions

10 of the binary digital code "level 1" and "level 0", and evaluates the signal-to-noise ratio coefficient that is calculated as the ratio of the difference between the mean values of the intensities at the "level 1" and "level 0" to the sum of the standard deviations at the "level 1" and

15 "level 0".

Although the configuration of FIG. 28 is simple, the applicable optical signal bit rate is limited by the bandwidth of the photoelectric converter 402.

On the other hand, in the configuration employing the

20 optical sampling oscilloscope 414 as shown in FIG. 29, the optical sampling oscilloscope 414 obtains the signal intensity distribution in a fixed time period, and then the signal processor 416 carries out the signal-to-noise ratio coefficient evaluation. The optical sampling

25 oscilloscope 414 can use for the optical signal intensity distribution measurement the optical sampling described in the reference material [3].

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The optical sampling is characterized by utilizing the second-order harmonic optical signal generation, sum frequency optical signal generation, difference frequency optical signal generation, or four wave mixing to obtain

5   the cross-correlation signal, and obtains the signal intensity distribution from the cross-correlation signal.

For example, the optical sampling oscilloscope 414, using the optical signal with the bit rate f_0 (bits/s) and the optical sampling pulse train whose repetition

10   frequency is f_1 (Hz) ($f_1 = (N/M)f_0 + a$, where N and M are an integer, and a is an offset frequency), and whose pulse width is sufficiently narrower than the time slot of the optical signal, generates the cross-correlation optical signal with an optical frequency different from that of

15   the two optical signals, converts the cross-correlation optical signal into an electric signal, carries out the opto-electric conversion of the cross-correlation optical signal, and then measures the intensity distribution of the optical signal in the fixed time period by performing

20   the electric signal processing.

The signal processor 416 comprises a histogram evaluating section 418 and a signal-to-noise ratio coefficient evaluating section 420. The histogram evaluating section 418 obtains the amplitude histogram

25   from the signal intensity distribution the optical sampling oscilloscope 414 produces. The signal-to-noise ratio coefficient evaluating section 420 calculates from

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the amplitude histogram the distributions of the binary digital code at the "level 1" and "level 0", and evaluates the signal-to-noise ratio coefficient that is calculated as the ratio of the difference between the mean values of the intensities at the "level 1" and "level 0" to the sum of the standard deviations at the "level 1" and "level 0".

The configuration of FIG. 29 is applicable to faster optical signal than that of FIG. 28 is.

Next, FIGs. 30A-33B illustrate examples of the signal-to-noise ratio coefficient measurement algorithm of the signal-to-noise ratio coefficient measuring section 222 for carrying out the optical signal quality monitoring.

FIG. 30A: The optical sampling oscilloscope 414 and the electrical sampling oscilloscope 404 obtain the intensity distribution within a certain mean time by the optical sampling and electric sampling, respectively.

FIG. 30B: Obtain the amplitude histogram from the intensity distribution calculated.

FIG. 31A: Decide a relative maximum value m0' when searching the amplitude histogram from its smallest intensity level.

FIG. 31B: Integrate the number of the sampled points from the sampling point that has a maximum intensity level toward smaller intensity level.

$$N(middle) = N(total) \times D \times M \qquad \cdots(1)$$

where N(total) is the total number of the sampling points, D is the duty ratio of the optical signal (the ratio between

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the pulse width and the time slot), and M is a mark ratio
(the probability of the occurrence of the level 1 in the
digital transmission).

When the integral value becomes equal to the number
of the sampling points N(middle) obtained by expression
(1), the minimum level of the integrated sampling points
is denoted by m(middle).

FIG. 32A: Determine m1' by the following expression
(2).

$$m1' = 2 \times \{m(middle) - m0'\} \qquad \cdots (2)$$

FIG. 32B: Determine the intensity levels obtained by
the following equations (3) and (4) as the threshold values
A and B.

$$A = m1' - alpha(m1'-m0') \qquad (3)$$
$$B = m0' + alpha(m1'-m0') \qquad (4)$$

where alpha is a real number of $0 < alpha < 0.5$. The
distribution whose intensity level is equal to or greater
than A as the "level 1" distribution, and the distribution
whose intensity level is equal to or less than B as the
"level 0" distribution.

FIG. 33A: Calculate mean values m1 and m0 and standard
deviations s1 and s0 for the "level 1" and "level 0"
distributions determined in FIG. 32B.

FIG. 33B: Calculate the Q value from the mean values
and standard deviations obtained in FIG. 33A by the
following equation (5), and make it as the signal-to-noise
ratio coefficient and quality evaluation parameter.

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$$Q = |m1-m0|/(s1 + s0) \qquad (5)$$

FIG. 34 illustrates experimental data of the signal-to-noise ratio coefficient obtained through the procedure as illustrated in FIGs. 30A-33B. The data were obtained using a 10 Gbits/s NRZ signal and electric sampling. The value alpha was set at 0.3. The horizontal axis represents the Q values that are obtained by converting the bit error rates (BER) measured, and indicate the actual variation in the optical signal quality because of noise. The vertical axis represents the signal-to-noise ratio coefficients calculated by the algorithm of FIGs. 30A-33B.

FIG. 34 shows that the signal-to-noise ratio coefficients, which use the optical signal quality monitoring in FIG. 28 and FIGs. 33A-33B, can be utilized as the parameters for detecting the SNR degradation, and hence as the monitor information to make the route switching.

FIG. 35 illustrates experimental data under the effect of the wavelength dispersion. As in FIG. 34, the data were obtained using a 10 Gbits/s NRZ signal and electric sampling. The value alpha was set at 0.3. The horizontal axis represents the Q values that are obtained by converting the bit error rates (BER) measured, and indicate the actual variation in the optical signal quality because of noise. The vertical axis represents the signal-to-noise ratio coefficients calculated by the

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algorithm of FIGs. 30A-33B. In FIG. 35, triangles plotted indicate the case where the wavelength dispersion value the optical signal undergoes is 0 ps/nm, and circles plotted indicate the case where the wavelength dispersion

5   value the optical signal undergoes is 1400 ps/nm.

FIG. 35 shows that the signal-to-noise ratio coefficient utilizing the optical signal quality monitoring has sensitivity to the waveform distortion caused by the wavelength dispersion, and to the SNR

10 degradation in the state of the waveform distortion caused by the wavelength dispersion.

(17th Embodiment)

FIGs. 36A and 36B each show an optical network configuration of a 17th embodiment in accordance with the

15 present invention. In particular, the present embodiment is an example that carries out the fault detection on an optical amplifying repeating section basis in the case where the optical amplifying repeating is performed between the optical transmit/receive terminals. FIG. 36A

20 shows a ring type optical network with a standby circuit 510, including an optical ADM ring; and FIG. 36B shows a mesh type optical network.

In both the optical networks in FIGs. 36A and 36B, each optical node 502 constituting the optical network

25 includes a pair of or multiple pairs of optical signal transmit terminal and optical signal receive terminal (transmit/receive terminals 504). An optical signal is

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terminated between the optical signal transmit terminal 504 of an optical node and the optical signal receive terminal 504 of another optical node. The optical networks include the case where the optical signal passes through the optical node 502.

As in the foregoing 16th embodiment, the optical signal receive terminal carries out the optical signal monitoring, and transmits the monitor information to the optical signal transmit terminal via the control channel between the optical transmit/receive terminals. Thus, the optical signal transmit terminal carries out the fault detection.

FIGs. 37A and 37B show an internal configuration of the optical transmit/receive terminal 504 of FIGs. 36A and 36B. Here, the components having the same functions as those of FIG. 26 of the 16th embodiment are designated by the same reference numerals. Receiving a signal from a higher level optical layer, the optical transmitter 604 of an optical signal transmit terminal 602 sends it to the transmission line 212 via the route switching section 606. In an optical signal receive terminal 216, an optical signal monitoring section 220 carries out the optical signal monitoring by utilizing part of the optical signal extracted. The optical signal monitoring section 220 comprises a signal-to-noise ratio coefficient measuring section 222, an initial state storing section 224 and an optical signal quality evaluating section 226, and carries

out the fault detection in a procedure as shown in FIG. 39 which will be described later.

It is assumed here that the optical branching circuit 218 corresponds to the configuration without the electric signal processor 19 or 26 of FIGs. 10-20 of the foregoing fourth, fifth, seventh, eighth and 11th embodiments in accordance with the present invention. The optical signal monitoring section 220 corresponds to the section in the electric signal processor 19 or 26 that carries out the quality evaluation parameter of the foregoing fourth, fifth, seventh, eighth and 11th embodiments in accordance with the present invention.

FIG. 38 shows an internal configuration of the optical amplifying repeating system 506 of FIG. 37. The optical amplifying repeating system 506 comprises an optical amplifier 716 for amplifying the optical signal transmitted through the transmission line 212; an optical branching circuit 718 for extracting part of the optical signal amplified; an optical signal monitoring section 720 for monitoring the optical signal branched; and a monitor information control section 728 for transmitting the monitor information from the optical signal monitoring section 720 to the optical signal transmit terminal 602 via the control channel 212. The monitor information is obtained by the optical signal monitoring section 720 that performs processing of the part of the optical signal, which is extracted by the optical branching circuit 718

from the optical signal amplified. The optical branching circuit 712 may be placed before the optical amplifier 716.

The optical signal monitoring section 720 comprises a signal-to-noise ratio coefficient measuring section 722, an initial state storing section 724 and an optical signal quality evaluating section 726 as the optical signal monitoring section 720 of the optical signal receive terminal 216, and carries out the fault detection in the procedure as illustrated in FIG. 39 which will be described below.

Next, the operation of the 17th embodiment in accordance with the present invention will now be described with reference to the flowchart of FIG. 39. Here, steps corresponding to those of the foregoing 16th embodiment of FIG. 27 are designated by the same step numbers.

Step S1: In the optical signal receive terminal 216 and optical amplifying repeating system 506, the signal-to-noise ratio coefficient measuring sections 222 and 722 measure the signal-to-noise ratio coefficients at the system installation in a state without any failure.

Step S2: The initial state storing sections 224 and 724 each store the signal-to-noise ratio coefficient measured at Step S1.

Step S3: The signal-to-noise ratio coefficient measuring sections 222 and 722 in the optical signal receive terminal 216 and optical amplifying repeating system 506 measure the signal-to-noise ratio coefficients

at the predetermined time intervals after starting the system operation.

Step S4: The optical signal quality evaluating sections 226 and 726 compare the signal-to-noise ratio coefficients with those of the initial state storing sections 224 and 724 every time they are measured.

Step S5: The optical signal quality evaluating sections 226 and 726 supply the monitor information control sections 228 and 728 with the variations in the signal-to-noise ratio coefficients from the initial state as the monitor information. When it recognizes from the degree of variations in the signal-to-noise ratio coefficients that a failure takes place, it also supplies the monitor information control section 228 with warning information indicating that the route switching is required as the monitor information.

Step S6: The monitor information control sections 228 and 728 each transmit the monitor information to the monitor information control section 610 in the optical signal transmit terminal 602 via the control channel 214.

Step S71: The monitor information control section 610 of the optical signal transmit terminal 602 supplies a fault detection section 612 with the monitor information transmitted from the monitor information control sections 228 and 728 of the optical signal receive terminal 216 and optical amplifying repeating system 506.

Step S72: The fault detection section 612 of the

optical signal transmit terminal 602 detects the section the signal degradation takes place from the monitor information sent from the optical amplifying repeating system 506 or optical signal receive terminal 216.

5   In this case, the route switching can be carried out as in the fourth embodiment in accordance with the present invention. In this case:

Step S73: The monitor information control section 610 of the optical signal transmit terminal 602 supplies the
10   route switching section 606 with information to make the route switching as needed, in accordance with the monitor information sent from the optical amplifying repeating system 506 and optical signal receive terminal 216.

Step S8: The route switching section 606 carries out
15   the route switching of the transmission line 212 in accordance with the instruction of the monitor information control section 610.

As the signal-to-noise ratio coefficient measuring sections 222 and 722 of FIGs. 37 and 38, it is possible
20   to use the optical signal quality monitoring described in the reference material [2]. As for the configuration of the signal-to-noise ratio coefficient sections using the optical signal quality monitoring and the measurement algorithm, they are the same as those of the 16th embodiment
25   in accordance with the present invention shown in FIG. 28-FIGs. 33A and 33B.

When the optical amplifying repeating system 506

employs the analog monitoring as in the 17th embodiment in accordance with the present invention, it comes to monitor the optical signal that does not undergo the dispersion compensation. As a result, it is not unlikely that it monitors the SNR degradation when the waveform distortion caused by the wavelength dispersion is large. In this case, however, the signal-to-noise ratio coefficients obtained by the optical signal quality monitoring can be utilized satisfactorily as illustrated in the data of FIG. 35. Thus, the signal-to-noise ratio coefficients obtained by the optical signal quality monitoring are available for the fault detection.

(18th Embodiment)

Next, FIGs. 40A-43 show, as an 18th embodiment in accordance with the present invention, another example of the algorithm of the signal-to-noise ratio coefficient measurement by the signal-to-noise ratio coefficient measuring sections 222 and 722 for carrying out the optical signal quality monitoring.

FIG. 40A: Obtain the intensity distribution in a certain mean time using the optical sampling by the optical sampling oscilloscope 414 with a configuration as shown in FIG. 29, or using the electric sampling by the electrical sampling oscilloscope 404 with the configuration as shown in FIG. 28.

FIG. 40B: Obtain the amplitude histogram from the

intensity distribution calculated.

FIG. 41A: Determine the first relative maximum value, which is obtained by searching the amplitude histogram from the greater intensity level side, as a threshold value A.

FIG. 41B: Determine the first relative maximum value, which is obtained by searching the amplitude histogram from the smaller intensity level side, as a threshold value B.

FIG. 42A: Obtain the mean value m1 and the standard deviation s1 of the level 1 by assuming that the portion with the intensity level equal to or greater than the threshold value A in the amplitude histogram takes a normal distribution g1, and by making fitting (approximation) of the normal distribution g1 using a least squares method or the like.

FIG. 42B: Obtain the mean value m0 and the standard deviation s0 of the level 0 by assuming as in FIG. 42A that the portion with the intensity level equal to or less than the threshold value B in the amplitude histogram takes a normal distribution g0, and by making fitting of the normal distribution g0 using a least squares method or the like.

FIG. 43: Calculate the Q value from the mean values m1 and m0 and the standard deviations s1 and s0 obtained in FIGs. 42A and 42B by the following expression (6), and make the Q value a signal-to-noise ratio coefficient, and adopt it as the optical signal quality evaluation parameter.

$$Q = |m1-m0|/(s1 + s0) \qquad (6)$$

As the distribution functions g0 and g1, it is also possible to assume a chi-square distribution (reference material [4]: D. Marcuse, "Derivation of Analytical Expressions for the Bit-Error Probability in Lightwave

5   Systems with Optical Amplifiers, "IEEE J. Lightwave Technol., Vol.8, No.12, pp1816-1823, 1990).

(19th Embodiment)

FIGs. 44A-47 shows, as a 19th embodiment in accordance with the present invention, another example of

10   the algorithm of the signal-to-noise ratio coefficient measurement by the signal-to-noise ratio coefficient measuring sections 222 and 722 for carrying out the optical signal quality monitoring. The present embodiment differs from the foregoing 18th embodiment in accordance

15   with the present invention in the calculation of the threshold values A and B in the entire algorithm.

FIG. 44A: Obtain the intensity distribution in a certain mean time using the optical sampling by the optical sampling oscilloscope 414 with the configuration as shown

20   in FIG. 29, or using the electric sampling by the electrical sampling oscilloscope 404 with the configuration as shown in FIG. 28.

FIG. 44B: Obtain the amplitude histogram from the intensity distribution calculated.

25   FIG. 45A: Determine the first relative maximum value, which is obtained by searching the amplitude histogram from the smaller intensity level side, as the threshold value

B.

FIG. 45B: Integrate the number of the sampling points from the sampling point with the maximum intensity level toward the smaller intensity level side. When the number of the sampling points N(middle) given by the following expression (7) becomes equal to the integral value, decide the minimum level of the levels at the integrated sampling points and make it m(middle).

$$N(middle) = N(total) \times D \times M \qquad (7)$$

where N(total) is the total number of the sampling points, D is the duty ratio of the optical signal, which is defined as a ratio between the pulse width and the time slot, and M is the mark ratio (the probability of occurrence of the "level 1" in the digital transmission).

FIG. 46A: Obtain the threshold value A by the following expression (8).

threshold value A

$$= 2 \times \{m(middle) - threshold\ value\ B\} \qquad (8)$$

FIG. 46B: Obtain the mean values m1 and m0 and standard deviations s1 and s0 of the level 1 and level 0 by assuming that the portion with the intensity level equal to or greater than the threshold value A in the amplitude histogram is a part of a normal distribution g1, that the portion with the intensity level equal to or smaller than the threshold value B is a part of a normal distribution g0, and by making fitting of the normal distributions g1 and g0 using a least squares method or the like.

FIG. 47: Calculate the Q value from the mean values
m1 and m0 and standard deviations s1 and s0 obtained in
FIG. 46B by the following expression (9), and make the Q
value a signal-to-noise ratio coefficient, and adopt it
5   as the optical signal quality evaluation parameter.

$$Q = |m1-m0|/(s1 + s0) \qquad (9)$$

As the distribution functions g0 and g1, it is
possible to assume a chi-square distribution (reference
material [4]).

10   Although the foregoing 18th embodiment in accordance
with the present invention has an advantage that it is the
simplest method, it is applicable only to NRZ signals. In
contrast with this, although the present 19th embodiment
is more complicated than the 18th embodiment, it is
15   applicable not only to the NRZ signals, but also to RZ
signals. However, it is necessary to know the duty ratio
and mark ratio of the signal pulses beforehand as shown
in equation (7).

20   (20th Embodiment)

FIGs. 48A-51 shows, as a 20th embodiment in
accordance with the present invention, another example of
the algorithm of the signal-to-noise ratio coefficient
measurement by the signal-to-noise ratio coefficient
25   measuring sections 222 and 722 for carrying out the optical
signal quality monitoring. The present embodiment
differs from the foregoing 18th and 19th embodiments in

91

accordance with the present invention in the calculation of the threshold values A and B in the entire algorithm.

FIG. 48A: Obtain the intensity distribution in a certain mean time using the optical sampling by the optical sampling oscilloscope 414 with the configuration as shown in FIG. 29, or using the electric sampling by the electrical sampling oscilloscope 404 with the configuration as shown in FIG. 28.

FIG. 48B: Obtain the amplitude histogram from the intensity distribution calculated.

FIG. 49A: Determine the first relative maximum value, which is obtained by searching the amplitude histogram from the smaller intensity level side, as the threshold value B.

FIG. 49B: Obtain the mean value m0 and standard deviation s0 of the level 0 by assuming that the portion with the intensity level equal to or less than the threshold value B in the amplitude histogram is a part of the normal distribution g0, and by making fitting of the normal distribution g0 using a least squares method or the like.

FIG. 50A: Obtain distribution g1x by subtracting the function g0 obtained in FIG. 49B from the entire amplitude histogram, and determine the first maximum value, which is detected by searching the distribution g1x from the greater intensity level side, as the threshold value A. The function g1x is considered to be a superimposed function of the distribution function g1 of the level 1

and the distribution function gx of cross-points.

FIG. 50B: Obtain the mean value m1 and standard deviation s1 of the level 1 by assuming that the portion with the intensity level equal to or less than the threshold value A in the distribution g1x is a part of the normal distribution g1, and by making fitting of the normal distribution g1 using a least squares method or the like.

FIG. 51: Calculate the Q value from the mean values m1 and m0 and standard deviations s1 and s0 obtained in FIGs. 50B and 49B by the following expression (10), and make the Q value a signal-to-noise ratio coefficient, and adopt it as the optical signal quality evaluation parameter.

$$Q = |m1-m0|/(s1 + s0) \qquad (9)$$

As the distribution functions g0 and g1, it is possible to assume a chi-square distribution (reference material [4]).

Although the present 20th embodiment is more complicated than the foregoing 19th embodiment, it is not only applicable to the RZ signals, but also has an advantage that it is not necessary to know the duty ratio and mark ratio of the signal pulses beforehand.

(21st Embodiment)

This embodiment shows an example of the system design for evaluating the average Q factor using asynchronous sampling. The system parameters are the sampling

resolution, the total number of samplings, the optical band-pass filter bandwidth, and the lowest BER limit which is optimized by using numerical calculation. Figure 52 shows the relationship between the standard deviation for

5   eight repeated evaluation points (vertical axis) and the total number of samplings used for the average Q factor evaluation (horizontal axis) of a B bit/s NRZ optical signal, when alpha is 0.3, the optical band-pass filter bandwidth is 4 $\times$ B Hz, the receiver bandwidth is 0.7 $\times$

10   B Hz, the sampling resolution is 1/256 $\times$ 1/B s, and the BER is 10^{-10}. As shown in Fig.52, the required number of total sampling points is approximately 15,000 points, when the standard deviation of 0.18 of less (this is converted into BER under the above-mentioned conditions and

15   corresponds to the maximum fluctuation between BER 10^{-9} and 10^{-10}) is assumed to be the requirement.

Figures 53A and 53B show the graph of the standard deviation and the average value for eight repeated evaluation points (vertical axis) depending on the

20   sampling resolution (horizontal axis), respectively, when the total number of samplings is 16,384 and the other conditions are the same as in Fig.52. Although the required resolution so that the standard deviation may achieve 0.18 or less is approximately 20 ps as shown in Fig.53A, when

25   the gap of the average Q factor is considered as shown in Fig. 53B, the required resolution becomes approximately 10 ps or less.

Figure 54A shows the dependence of the average Q factor on the Q factor of a B bit/s NRZ optical signal when alpha is 0.3, the receiver bandwidth is $0.7 \times B$ Hz, the sampling resolution is $1/256 \times 1/B$ s, the number of samplings is 16,384, and the optical band-pass filter bandwidth is $4 \times B$, $14 \times B$, $24 \times B$, or $40 \times B$ Hz. Figure 54B shows the dependence of the linear fitting slope of the average Q and Q relationship on the optical band-pass filter. The optical band-pass filter bandwidth can be set by referring to the figure.

As shown in the Fig.54B, linear fitting is possible between the average Q and the Q when Q is up to 20 dB, that is to say, the average Q factor evaluation is sufficiently sensitive to measure a signal with a considerably low BER (about 10^{-24}).

(Other Embodiments)

It is obvious that the object of the present invention is also achieved by supplying a system or apparatus with a recording medium that stores the program code of software for implementing the functions of the foregoing embodiments, and by causing a computer (or CPU or MPU) of the system or apparatus to read the program code stored in the storing medium, and to execute it. In this case, the program code itself read from the storing medium implements the functions of the foregoing embodiments, and the storing medium that stores the program code constitutes

the present invention. As the storing medium for storing the program code and variable data such as tables, a floppy disk or hard disk can be used, for example.

The present invention has been described in detail with respect to preferred embodiments, and it will now be apparent from the foregoing to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspect, and it is the intention, therefore, in the appended claims to cover all such changes and modifications as fall within the true spirit of the invention.